POWER PLANT ENGINEERING

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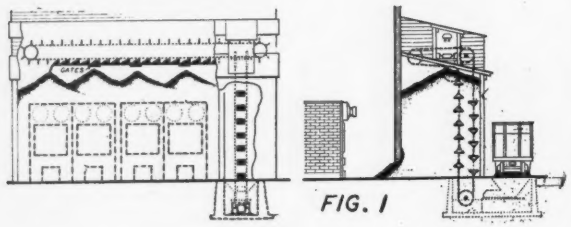
Power and Fuel Facts

Prime movers of all kinds in U. S. (Stationary and Locomotive)	100,000,000 hp.
Used at average load factor of	14%
Used for average period per week	23.5 hr.
Develop per year	125 billion hp.-hr.
Water power available	50,000,000 hp.
Coal (without lignite), in ground	2500 billion T.
Petroleum, in ground	7 billion bbl.
Used for power only (locomotive and stationary) on basis of present power delivered, resources will last:	
Water power, if all developed	indefinitely.
Coal used by best practice	57000 yr.
Coal used by average practice	7500 yr.
Petroleum (allowing 40% gasoline)	9.25 yr.
Of prime movers installed:	
Steam plants, coal fired make up	52%
Hydraulic plants, make up	8.2%
Combustion engines and other types, make up	39.8%
Of power developed:	
Public utilities use	42%
Manufacturing plants use	28%
Railroads use	30%
Of 1 ton of coal in the ground	2000 lb.
Best recovery brings to the surface	1900 lb.
Average recovery brings to the surface	1400 lb.
Poor recovery brings to the surface	1000 lb.
Power to operate the coal mine takes	100 lb.
Turned into useful work at point of application:	
By best large central stations	608 lb.
By best small central stations	304 lb.
By locomotives best practise	175 lb.
By small individual plants, average practise	76 lb.

Fuel Handling

A Comparison of Various Methods of Handling Fuel Economically in the Power Plant

AMONG THE VARIOUS factors requiring consideration in a study of power plant economics, the subject of fuel handling is one which is of prime importance. While cost of fuel is, without doubt, the largest item of expense in any steam power plant, to the cost of coal must be added the cost per ton of handling it. The price of the fuel itself is fixed by external conditions over which the management of the plant has no control, but the cost of transferring it from the point of delivery to the furnace is dependent upon the design of the plant and upon the efforts of the operating force.



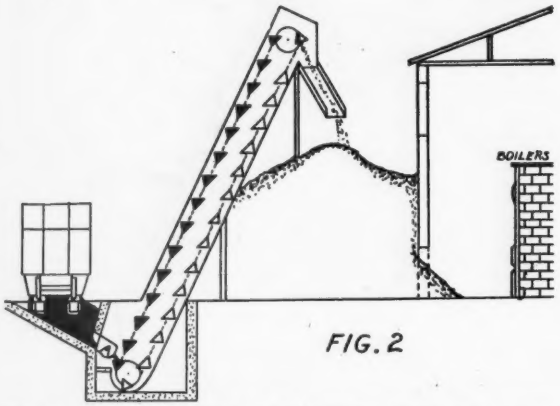


FIG. 1. SIMPLE METHOD OF HANDLING FUEL IN A HAND-FIRED PLANT

FIG. 2. HANDLING FUEL IN A HAND-FIRED PLANT WITH A BUCKET ELEVATOR

While the question of transportation from the mine to the plant is also of vital importance, the scope of this article allows only a discussion of handling the fuel within the confines of the power plant itself, in other words, from the point of delivery to the furnace.

Because coal can frequently be conveyed more cheaply by water than by rail large power plants are often located upon navigable waterways, if it is convenient to do so, and, if not, the site should, when practicable, be located adjacent to a railroad so that fuel can be delivered to the plant at minimum expense. The two conditions generally require different systems of handling the coal at the plant, inasmuch as barges or ships lend themselves more readily to the use of grab buckets when unloading while with railroad cars, other means are usually employed.

The expenditure to which one should go in providing equipment for handling coal in any power plant, of course, depends entirely upon individual circumstances and upon the amount of coal to be burned, as in some cases the cost of handling coal may be so small compared to other expenses as to be of secondary consequence. But expenses of installation or operating costs are not always the most important factors to be considered. The insurance against forced "shut-downs" due to labor troubles may be sufficient reason for incurring considerable expense in providing coal handling apparatus. Each case requires its separate solution. In large stations the amount of coal handled, in practically every case, warrants the expense of elaborate conveyor systems, the installation of which would not be justified in smaller plants. Even in the smallest plant, however, thought should be given the matter of coal delivery.

When located along a railway line, a sidetrack must be provided so as to switch the cars from the main line when unloading. Provision must in all cases be made for unloading by hand, since the furnishing of bottom dump cars by the railroad companies can not be depended upon. The methods in use at present, like all other stages of the coal handling situation, are more or less in state of transition between the old custom of shoveling out all cars by hand and the modern methods of unloading by dump cars run on trestles or over hoppers and by grab buckets, conveyors, and other appliances. Owing to this diversity of conditions, the railroads find it almost impossible to arrange the distribution of cars to satisfy all. They are called upon to furnish modern plants entirely with modern cars and the old-fashioned plants with shovel-out cars. As a result, the consumer installing a trestle has to figure on having from 10 to 35 per cent of his coal delivered to him in shovel-out cars, and the full economy of his modern apparatus is not realized.

If coal handling machinery is not used, it is a convenient arrangement to have coal pockets or coal bunkers next to the wall of the boiler room so that the coal will fall from them by gravity to the floor in front of the furnace doors.

Handwork

Except in small plants of about 500 hp. and under, hand firing and the manual handling of coal is being done away with. With the high cost of labor at the present time, the amount of coal handled even in a plant of moderate size will justify the installation of some form of mechanical apparatus.

In the layout of a hand-fired installation, wherever possible, arrangements should be made for delivering coal directly into bunkers or bins in front of the boilers.

Two arrangements for use in connection with hand fired installations are shown in Figs. 1 and 2. In the first, coal delivered into a track hopper is elevated by a bucket elevator and then delivered to a horizontal flight conveyor which distributes it in bunkers located directly in front of the boilers. By opening slides, the

coal falls on the boiler room floor and is shoveled into the furnaces by hand.

The second arrangement, while not as desirable as the one just described, is nevertheless inexpensive to install and in small plants may be the most economical solution to the coal handling problem. In this case, coal is discharged from the track hopper directly into the inclined bucket elevator which discharges into an open storage bin next to the boiler room wall.

Where coal can not be stored in this manner or in overhead bunkers, it must be handled by wheelbarrow or cart and dumped on the fire-room floor. For distances of over 100 ft. and quantities over 20 tons per day, the cost of handling in this manner may warrant the installation of a conveyor system. It is difficult to give a general rule for drawing the line, however. The practical limits of economical hand firing depend upon individual circumstances. It is not necessarily a factor of the number of boilers used. Where one plant may find it economical to use mechanical stokers for two boilers, another plant in the same locality may serve from 6 to 10 large boilers economically by hand. With coal delivered in front of the furnaces, one man besides an engineer and a night man can run an engine and fire up to about 35 tons per week. With two men, an engineer and a night man, about 80 tons can be handled in this manner. These figures assume that the night man does all he can of the banking, cleaning and starting.

Even with modern conveying and unloading machinery, hand shoveling sometimes becomes necessary due to the freezing of the coal in the cars or storage piles. This is especially true of washed coals and sometimes where this coal is stored out of doors, dynamite has to be used to break it.

Mechanical Handling

The type of apparatus to be installed for the mechanical handling of coal in any power plant will vary in accordance with the conditions prevailing at the plant under consideration. No hard and fast rules can be laid down for selecting any particular type of apparatus until a careful study has been made of the local conditions. An accurate knowledge of the methods and costs of the hand work which it is desired to replace is essential in considering the installation of mechanical equipment.

With any proposed installation, however, the sum of the three items, operating costs, maintenance costs, and interest on the money invested, must be less than the cost of handling the coal before the system was installed. This is a fundamental requirement and unless it is attained the system fails in its purpose.

First cost, while important, is not always a deciding factor and should not be the sole reason for failing to provide coal handling machinery. Of course, initial cost should in all cases be given due consideration, but not until ascertaining just how much of a saving can be effected by the use of conveying equipment should any proposed system be rejected. Similarly, the economies effected by existing mechanical installations should also be carefully determined in order to know whether such economies could not be greatly increased by substituting conveyors of improved design. It must be remembered that the boiler room is the last place in which to install cheap equipment; a little more money spent in the first place may mean a large saving later on.

In a plant equipped with mechanical stokers, there is a further saving to be obtained from the use of automatic feeding apparatus due to the increased efficiency of the boilers. This increase in boiler efficiency is obtained by the proper sizing of the coal, so that it will be most suitable for the particular type of stoker, and by arranging a proper feed to the stokers so that the operators can give their entire attention to operating the stokers without the task of breaking up lumps of coal. This question of good or bad firing is important, and it often amounts to a difference of 15 per cent in the amount of fuel consumed in the plant.

Besides the direct economies brought about by its use, conveying machinery possesses other important advantages. It reduces the uncertain element of labor with its consequent "shut-downs" to an insignificant

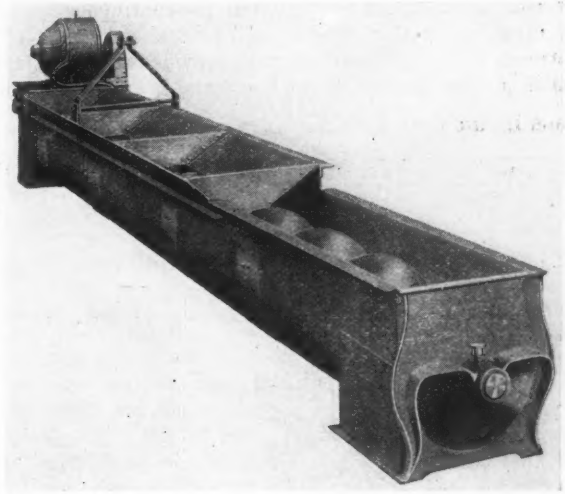


FIG. 3. SCREW OR SPIRAL CONVEYOR

factor. It promotes cleanliness and neatness in the fire-room, resulting in greater conscientious effort on the part of the employes. In plants where space is at a premium, the installation of a suitable conveyor system may increase the available storage capacity two or three fold. These advantages together with the reduction in operating expenses make the installation of some form of coal handling machinery well worth considering, even in plants of small or moderate size.

Types of Equipment

In selecting the type of equipment for the handling of coal in the power plant, it will be necessary to decide upon the question of separating the coal and ash handling machinery or of combining them into one system. In large plants where the amount of coal handled is sufficient to require almost continuous day-time operation of the coal handling machinery, it is imperative that a separate system be provided for ashes. In fact, in a plant of such size it is advisable to provide duplicate equipment or an alternative method for coal handling to insure uninterrupted service at all times.

In moderate size plants, where the coal is handled

only a few hours each day, it will probably be best to employ a single carrier for both coal and ashes, so that they can be handled alternately. With certain types of conveyors, however, where the abrasive effect of the ashes would seriously impair the life of the apparatus, a separation of the two systems may be the most economical arrangement.

Since the amount of coal handled is usually about five times the amount of ashes handled, in small plants the amount of ashes handled may be so insignificant as to need no mechanical apparatus for its disposal. In such cases, a conveyor system should be installed primarily for the handling of coal.

Apparatus for the mechanical handling of coal in the power plant may be divided, broadly, into two classes: First, systems in which coal is handled continuously, such as belt or bucket conveyors, and, second, systems in which it is handled at more or less regular intervals, such as grab buckets and trolley carriers.

Of the two classes in use in power plants, probably the most common are conveyors of the continuous type. In plants with this type of equipment, some sort of overhead coal bin is nearly always provided so that after coal is put in the bin by the conveyor, it can be drawn

TABLE I. INCLINATION CONSTANTS FOR FLIGHT CONVEYORS

	Hor.	5°	10°	15°	20°	25°	30°	35°	40°	45°
A	0.343	0.42	0.50	0.585	0.66	0.73	0.79	0.85	0.90	0.945
B	0.01	0.01	0.01	0.01	0.009	0.009	0.009	0.008	0.008	0.007

off by gravity and fed to the stokers with little or no hand labor.

The following are the more common of the various systems in use:

1. Continuous conveyors.
   - (a) Screw or spiral.
   - (b) Flight or scraper.
   - (c) Apron and buckets.
   - (d) Pivoted buckets.
   - (e) Endless belt.
2. Electric larry.
3. Hoists.
4. Hoist and trolley: telpherage.
5. Cranes.
   - (a) Railroad with clam shell bucket.
   - (b) Transfer with clam shell bucket.

Conveyors of the continuous type may further be divided into two general classes:

(a) Those which push or pull their load, the weight of the load not being borne by the moving parts of the conveyor.

(b) Those which actually carry the material handled.

One disadvantage of the class of conveyors which push or pull the coal or other material along in a trough is that the friction of the conveyor itself and the material conveyed on the trough consume power and cause excessive wear. The carrier type is usually more economical of operation.

Flight or Scraper Conveyors

While not by any means the most efficient type of conveying apparatus, the flight or scraper conveyor may, under certain conditions perform the work economically. This is especially true where first cost of the apparatus is of paramount importance.

The flight conveyor is a form of pusher type and in its simplest form consists merely of an endless chain, or chains, to which are attached at intervals scrapers or flights. The flights either slide directly on the trough or else they are fitted with shoes or rollers which travel on tracks at the sides. In the latter type, the flights run along very close to the bottom of the trough but not actually touching it, thus reducing the friction upon the trough to that of the material conveyed only. Roller flights are a very desirable type for the handling of coal and are used to a great extent. The coal is easily discharged at different points by opening sliding doors fitted in the bottom of the trough. Scraper conveyors are limited to about 300-ft. lengths, and the common working speeds are from 100 to 200 ft. per min. In some cases, they are able to handle 500 tons per hour.

The approximate capacity of this type of conveyor can be determined from the area of flights. For each square inch of flight area, with flights spaced one foot apart and when running at 100 ft. per min., the conveyor will have a capacity of about 1.25 tons. A conveyor operating at an inclination of 10 deg. to the horizontal is capable of carrying but 80 per cent of the capacity of a level conveyor; one inclined 20 deg. only about 67 per cent, while an inclination of 30 deg. reduces the capacity to 50 per cent.

The size of coal to be handled must be considered when selecting the size of conveyor. As an example, run-of-mine coal cannot be handled economically on a flight conveyor less than 18 in. wide.

TABLE II. VALUE OF CONSTANTS IN CONVEYOR POWER FORMULAS

Angle of Conveyor with horizontal Deg.	Sliding Block	A			B Scraper, Apron and open top			B V-Bucket and Pivoted Bucket.		
		3½-in. Roller 2½-in. Pin.	6-in. Roller 1-½ in. Pin	6-in. Roller 1½-in. Pin	Anthracite Coal	Bituminous Coal	Ashes	3½-in. Roller 2-in. Pin	6-in. Roller 1-⅝ in. Pin	6-in. Roller 1½-in. Pin
0	0.030	0.0043	0.0046	0.0050	0.33	0.60	0.54	0.071	0.076	0.083
6	0.030	0.0043	0.0046	0.0050	0.43	0.69	0.63	0.17	0.18	0.19
12	0.030	0.0042	0.0045	0.0049	0.54	0.79	0.73	0.28	0.28	0.29
18	0.029	0.0041	0.0044	0.0048	0.63	0.88	0.82	0.38	0.38	0.39
24	0.028	0.0039	0.0042	0.0046	0.72	0.95	0.90	0.48	0.48	0.49
30	0.026	0.0037	0.0040	0.0043	0.79	1.02	0.97	0.57	0.57	0.58
36	0.025	0.0035	0.0037	0.0040	0.86	1.08	1.03	0.65	0.66	0.66
42	0.023	0.0032	0.0034	0.0037	0.92	1.12	1.07	0.73	0.73	0.74
48	0.020	0.0029	0.0031	0.0033	0.97	1.15	1.11	0.80	0.80	0.81

The horsepower required in handling anthracite coal may be determined from the following formula:

$$\text{Hp.} = (A\ T\ L + B\ W\ S) \div 1000 \ldots\ldots (1)$$

in which T = net tons per hour, L = length center to center in feet, W = weight, chain and flights (both runs) in pounds, S = speed in feet per minute.

A and B are constants depending on inclination from horizontal, taken from Table I.

In comparing the two types, roller against sliding shoe conveyors, the roller type will be found more economical, in spite of its increased initial cost. The saving in power and the lower maintenance and depreciation charges further recommend the roller flight conveyor. It will be found that the sum total of all the expenses, the net operating cost, is slightly more for the sliding shoe type than for the more efficient construction.

V-Bucket Conveyor

The V-bucket conveyor, also known as the gravity-discharge conveyor, is a modification of the flight con-

veyor in which the flights are given the form of buckets rigidly fastened to the conveyor chain. With this type the material will fall back into the buckets when the conveyor makes an upward turn and is thus elevated. When following a horizontal path the material partly flows out and is dragged ahead of the bucket as in the ordinary flight conveyor. This machine, then, has the advantage of combining the ability to handle coal both horizontally and vertically. It is low in cost of installation and is well adapted for use in smaller plants. The horsepower required for these machines is given approximately by the following empirical formula, due to C. K. Baldwin:

$$Hp. = (AWL'S + BL_1T + TH) \div 1000 + \tfrac{1}{2}x'$$

in which L′= horizontal length of conveyor, ft.,

L_1= total horizontal length traversed by the loaded bucket, ft.,

H = total vertical traverse, ft.,

W= weight of conveyor per ft. of run, lb.,

S = speed of conveyor ft. per min.

T = capacity of conveyor, tons per hr.,

x′ = number of 90-deg. turns in conveyor,

A, B= constants as in Table II.

Bucket Elevators

The bucket elevators, of which there are several on the market, are modifications of the V-bucket conveyor in which the chief difference is in the shape and spacing of buckets, the methods of discharging, and the ability to convey material horizontally.

One type of bucket elevator is known as a centrifugal discharge elevator. It consists of a single or double chain with buckets attached running over sprocket wheels. At the bottom the coal is dipped up from a hopper and at the top discharge is effected as the buckets pass over the sprocket wheel. The speed of this elevator must be carefully regulated to obtain effective discharge. If the speed is too slow, the material will fall out of the buckets too soon, and if it operates too fast, the material will be carried over and thrown straight down instead of being caught in the chute. Another type of elevator is known as the continuous bucket elevator. This is suitable for use with high capacities at slow speeds. The buckets are constructed in such a manner as to guide the material into the discharge chute at the top and the effectiveness of discharge is not affected by the speed of the machine.

Machines of this type are used in many cases, in connection with some other horizontal type of conveyor, the elevator discharging onto a belt or flight conveyor as it reaches the limit of its vertical travel. Such an installation is shown diagrammatically in Fig. 1.

The size of a bucket elevator necessary at any plant is dependent upon three factors: first, the size of the buckets; second, the number of buckets; and third, the speed of the elevator.

The first condition has been fairly well standardized since the coal to be elevated is almost invariably of a small or medium size. The second condition is determined by the ability of the buckets to pick up a suitable load as they revolve around the tail sprocket at normal speed. The third point is dependent upon the type of elevator, since, if of the centrifugal type, the speed is fixed by that necessary to obtain effective discharge, and by economic power requirements.

Since the constructional features of these elevators vary considerably with regard to different types and sizes, the initial cost will vary accordingly. A double chain elevator will cost more than a single chain elevator due to its greater number of parts and usually, its greater size. The buckets can be furnished either of malleable iron or steel, and although malleable iron buckets are considerably more expensive than steel buckets, they are usually more durable. The elevator may be enclosed in a steel or wooden casing or it may run exposed. These variables all affect the first cost and must be figured separately when selecting the apparatus.

The cost of operation of a bucket elevator system or of any conveyor system, for that matter, may be divided into three separate items: the cost of operation, the cost of maintenance, and the interest on the money invested. The operating costs include the expense of power

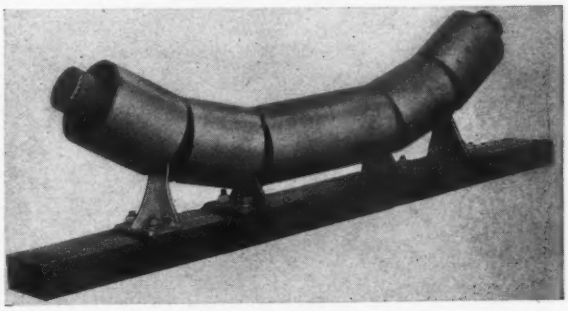


FIG. 4. FIVE-PULLEY IDLER FOR BELT CONVEYOR

and labor, together with the cost of supplies necessary to keep the system in good working order. The power required depends upon the amount of coal handled, and its cost upon the cost of fuel and the efficiency of the plant. The cost of labor must be so proportioned that a fairly constant charge may be made against each ton of material handled to cover such expense. Costs of supplies and repair parts vary with the amount of power consumed and may therefore be divided so that a fair charge can be made against each ton of material handled. The average cost of operation may be said to consist of two general charges, one depending upon the cost of power and the other upon the tonnage handled. Both cost, maintenance and burden depend upon the initial cost of the outfit, but this in turn depends upon the size of the buckets and may therefore be expressed in terms of tons handled per hour by the elevator or a certain charge made against each ton elevated.

While the bucket elevator is not the only apparatus by which the operation of raising a load from one level to a higher one can be performed economically, it is a system which requires least space of installation and is usually the most logical system to employ.

The power requirements are easily determined since it is simply a matter of ascertaining the number of foot pounds of work done by multiplying the load by the distance through which it is elevated. Losses due to friction may be assumed to be one-third of the total power required by the elevator under load. This includes the friction of the buckets through the material to be elevated.

The above relations are conveniently expressed as follows:

$$\text{Hp.} = \frac{WH}{666} \qquad (3)$$

where Hp. = horsepower required.
W = weight of load elevated in tons per hr.
H = height to which load is elevated.

Screw or Spiral Conveyor

Screw or spiral conveyors are not well adapted to the handling of coal in power plants. On account of their low first cost, however, they are used to some extent for the handling of the smaller grades of coal over comparatively short distances, and, in confined places, where compactness is necessary, the screw conveyor may be the only solution to the coal handling problem.

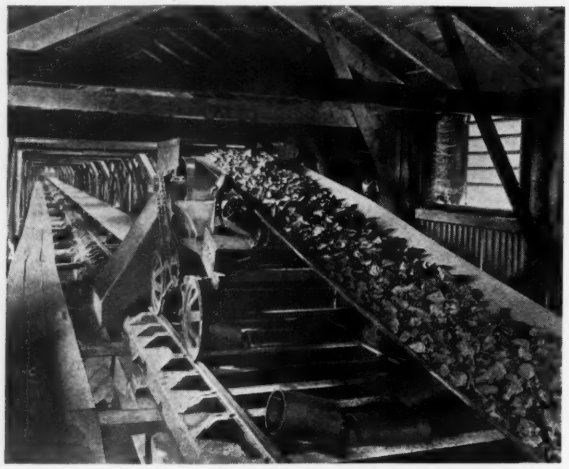


FIG. 5. TYPICAL BELT CONVEYOR INSTALLATION SHOWING TRAVELING TRIPPER

In plants where the main storage is contained in overhead bunkers, the boilers may be so located as to make it difficult to feed the coal to the stokers. This may be due to alterations in the original design of the plant or space limitations. In such cases, screw conveyors are economically installed for feeding the stoker hoppers both on account of compactness and the slow rate of feed possible.

This conveyor consists of a steel ribbon wound spirally around a shaft which fits in a trough or cylinder so that the edges of the spiral are quite close to, but not in actual contact with the trough. As the shaft with screw attached revolves, coal or other material delivered at one end of the trough is gradually pushed to the other end. The material can be discharged either at the end or at a number of intermediate points through sliding doors in the bottom of the trough.

The shaft, which is generally a wrought iron tube for the sake of lightness and strength, should be supported at the ends in long bearings and also at intervals along its length. These conveyors are usually used horizontally, but may be employed up to an angle of about 15 deg. to the horizontal. In practically every installation of screw conveyors, however, some other type of elevating apparatus is required, as this type of apparatus can be inclined only a small amount without sacrificing its mechanical efficiency.

As has been stated, the chief advantage of this conveyor lies in its low first cost and its adaptability in confined quarters. These advantages, however, may be balanced by the disadvantage of excessive power requirements and high cost of maintenance. The frictional losses are high and there are frequent breaks due to foreign material jamming at the shaft bearings. On account of the torsional strains on the shaft, screw conveyors are not usually employed for lengths exceeding 100 ft. Furthermore, only coal of small size can be handled efficiently by this type of conveyor.

One modern application of the screw conveyor is in its use with powdered coal installations. Powdered coal lends itself admirably to the use of the screw conveyor and as the equipment can be entirely enclosed, the amount of dust liberated is reduced to a minimum.

The initial cost in terms of tons handled per hr. of a screw conveyor installation may be closely approximated from the capacity in tons per hr. and its size. The cost does not vary directly with its size nor with its capacity, as a larger size screw conveyor is operated at a slower speed than a small one. Cast-iron troughs cost more than steel, but the difference is about constant; that is, the additional cost is about proportional to the size of the conveyor.

Table III gives a fair idea of the conveying capacities.

Table III. Capacities of Spiral Conveyors in Cubic Feet of coal conveyed per hr. at 100 r.p.m.

Diam. In.....	6	8	10	12	14	16
Capacity	260	660	1000	1660	2500	3660

The horsepower required for driving is given by the following formula:

$$\text{Hp.} = \text{Cap. in lb. per min.} \times \text{length in ft.} \times f \div 33{,}000 \qquad (4)$$

For anthracite coal, $f = 0.67$.

Belt Conveyors

Of the various types of continuous conveyors which carry their load, one of the simplest and perhaps one of the oldest which is used quite extensively for handling coal is the belt conveyor. This consists essentially of an endless belt of canvas, rubber, or other material traveling over a number of pulleys. Material thrown on this moving belt will be discharged over the end or can be discharged at intermediate points by means of dischargers in which the belt is made to take a reverse turn around a tripper pulley.

Trippers may be either fixed or movable, and may be either hand propelled or power driven. When discharging coal into a long bin, such as is frequently used as an overhead bunker for feeding stokers, a traveling tripper is used. Such trippers are self-propelled, being driven by power taken from the conveyor belt, through suitable gearing to the truck wheels. A lever on one side properly connected with the driving mechanism controls the direction of travel of the tripper. This lever engages adjustable stops located on the rails at the desired limits of discharge and the machine will travel between these stops, automatically reversing at each end.

The early types of belt conveyors were perfectly flat, but later on, to increase the capacities without spilling material off the edges, the rollers on which the belt

traveled were made somewhat concave or dished, causing the belt to assume the form of a shallow trough. The modern types are made with idlers, shown in Fig. 4, consisting of a series of small pulleys of equal diameter arranged in the same or different planes. Such idlers will produce no wear due to slip, as is the case with the single concave roller. The belt, most suitable, is made of woven cotton duck covered with a special rubber compound on the carrying side. It must be remembered, however, that rubber belts are absolutely water-proof only when the cover is intact. The duck body of the belt absorbs water readily and belts of this kind are often ruined by the water reaching the duck through cuts or punctures in the rubber.

The belt conveyor is especially adapted for high capacities and long distance conveying, since the power consumption on long runs is comparatively low. On moderate capacities, however, the cost of maintenance is apt to be higher than when using flight conveyors, due to the high cost of belting.

Among the disadvantages of the belt conveyor may be mentioned the difficulty of loading, especially at high speeds. It is difficult to regulate the feed so as to distribute the coal over the belt evenly. Another disadvantage is the requirement of a more or less ponderous device for unloading.

L = length of conveyor between centers in ft.
H = vertical lift of material.

For each movable or fixed tripper add the horsepower given in Table IV.

Add 50 per cent to calculated horsepower for each conveyor under 50 ft. in length.

Add 20 per cent to calculated horsepower for each conveyor between 50 and 100 ft. in length.

TABLE IV. POWER REQUIREMENTS FOR BELT CONVEYOR

Width of belt, in.	12	14	16	18	20	22	24	26	28	30	32	34	36
C	.234	.224	.220	.209	.205	.199	.195	.187	.175	.167	.163	.161	.157
Hp. required for each movable or fixed tripper	.5	.5	.75	1.	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25

Add 4 per cent to calculated horsepower for each conveyor 500 ft. in length.

Pivoted Bucket Conveyors

An excellent arrangement and one most widely used for handling coal in steam power plants consists of a well designed pivoted bucket conveyor, an overhead coal bunker with spouts to the stokers, together with the customary track hopper and crusher.

Such an installation is shown diagrammatically in Fig. 6. Here the railroad track runs close to one end of the boiler house, and the track hopper into which the coal is discharged from the railroad cars is located underneath the track. From the hopper it is fed through a reciprocating feeder directly into a crusher and after being reduced to a suitable size for use in the stokers, the coal falls on the apron conveyor as shown. This apron conveyor transfers the coal to a point directly over the bucket carrier into which it is delivered. The carrier follows a rectangular path with the upper run above the overhead coal bin, the lower run along the basement floor, the ascending run just inside the railroad track and the descending run coming down just inside the opposite wall of the boiler room. The coal is elevated and distributed in the overhead bin by the carrier buckets, the discharging of the buckets being accomplished by a movable tripper running on a T-rail below the upper run of the carrier.

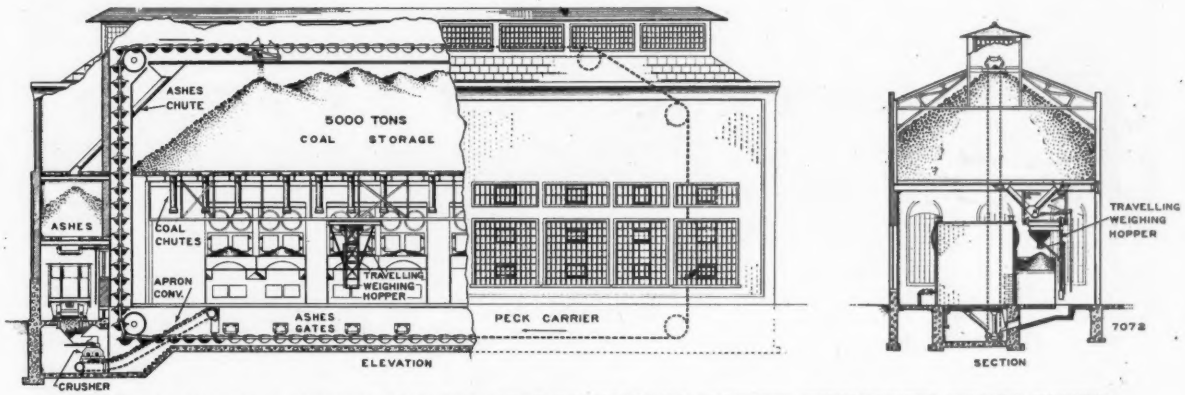


FIG. 6. DIAGRAM OF A MODERN COAL HANDLING INSTALLATION EQUIPPED WITH PIVOTED BUCKET CARRIER, APRON CONVEYOR AND CRUSHER

The advantages of the belt type of conveyor, however, must not be lost sight of when enumerating the foregoing disadvantages. Its ability to handle large loads and its simplicity, especially as regards methods of drive has made its use popular in the larger size power plants. Drive is effected by simply connecting an electric motor to one of the pulleys. Conveyors of from 700 to 1000 ft. from center to center, have been successfully operated at capacities of 500 tons per hr. It is not feasible, however, to operate them at an incline over about 18 to 20 deg. as the coal is apt to slide back.

For figuring the power requirements for the belt conveyor approximately, the following empirical equation due to C. K. Baldwin may be used:

for level conveyors,

$$\text{Hp.} = \text{CTL} \div 1000 \qquad (5)$$

For inclined conveyors,

$$\text{Hp.} = (\text{CTL} \div 1000) + (\text{TH} \div 1000)$$

in which C = constant as given in Table IV.
T = load in tons per hr.

coal out of the cars into the track hopper. Furthermore, with the exception of the feeder and crusher, the work is done with only one machine. Attendance and maintenance costs are thus reduced to a minimum. Since the up and down runs balance each other, except for the material in the buckets and on account of the large rollers, little power is required to operate such a carrier. A conveyor of this type capable of handling 60 tons of coal an hour requires approximately 7½ hp. to run it. The crusher and feeder will require about double this amount or 15 hp.

Equipment of this type generally consists of a series of malleable iron buckets of the form shown in Fig. 7 freely suspended at their ends upon pins between two strands of chains so as to overlap each other upon lips extending from the buckets. Being suspended to pivot freely, the buckets will necessarily carry level in all horizontal, all inclined and all vertical positions of the chains. Thus as described in the foregoing, a series of buckets can be filled in a basement from under a hopper or chute, be carried for a distance along the basement floor to the end of the building and thence raised up and over a bin or storage space. There the buckets, one after another, are emptied at any point along the upper run by means of stationary or movable trippers, or extended arms which engage dumping cams upon the ends of the buckets. This dumping action is illustrated in Fig. 10. The buckets being suspended or pivoted near their tops will quickly right themselves after being dumped. This type of conveyor, thus, combines both an elevator and one or more horizontal conveyors in a single machine.

Either stationary or movable trippers, or both, may be employed with bucket carriers. The stationary tripper is used primarily where there is but one point of discharge, whereas the traveling tripper is used where a long coal bin is to be completely and uniformly filled. Therefore, in the boiler house installation both trippers in many cases are used, the stationary tripper being located over the ashes bin, somewhat removed from the coal storage over which the traveling tripper operates. This separate stationary tripper has been found to be a time saver, even where the traveling tripper could readily be extended over the ashes bin, as quite often the traveling tripper may be dumping coal at the far end from the ashes bin, when the carrier is suddenly required to handle ashes. Much time is then lost in moving the traveling tripper back and forth over the whole length of the carrier before the dumping of coal can be resumed. It is customary to move a traveling tripper

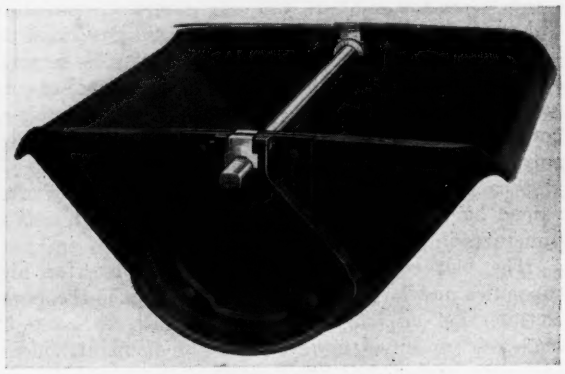


FIG. 7. TYPE OF BUCKET USED ON THE PIVOTED BUCKET CONVEYOR

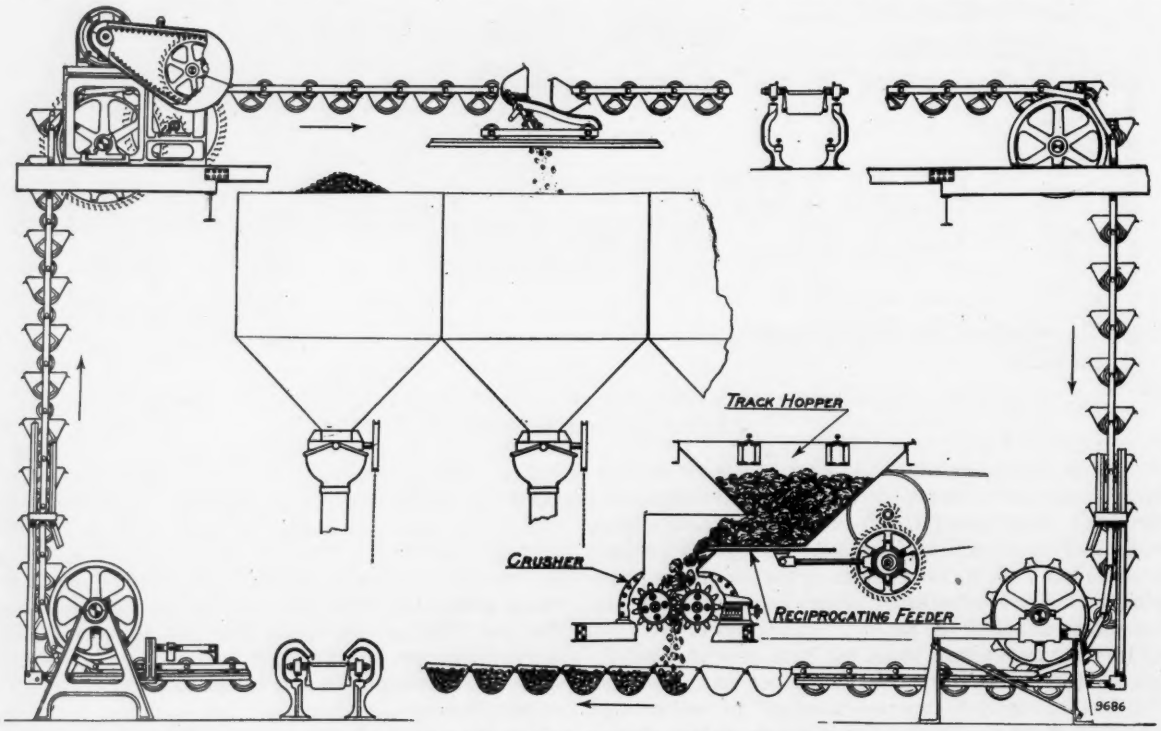


FIG. 8. DIAGRAM OF THE PIVOTED BUCKET CARRIER

but a few feet at a time. Stationary trippers are often used where the coal storage is comparatively short—two or three trippers being so spaced in consideration of the coning angle of the coal. On the other hand, over a long storage it is quite apparent that the range of service and cost of a single traveling tripper measured against the cost of a number of stationary trippers, is much in favor of the former.

The differences in the various makes of this type of carrier consist mostly in the method of driving, method of emptying and in the method of closing the gaps between adjacent buckets to prevent spilling.

Among the various devices used for filling the buckets may be mentioned the revolving drum type, the reciprocating plate type, and the continuous type, the latter being used only when the individual buckets overlap so as to make a continuous apron. The revolving drum type consists of a cylindrical drum with an opening in it. As the drum revolves in synchronism with the carrier, just enough material is discharged from the drum at each revolution to fill a carrier bucket. Each bucket thus receives an equal charge.

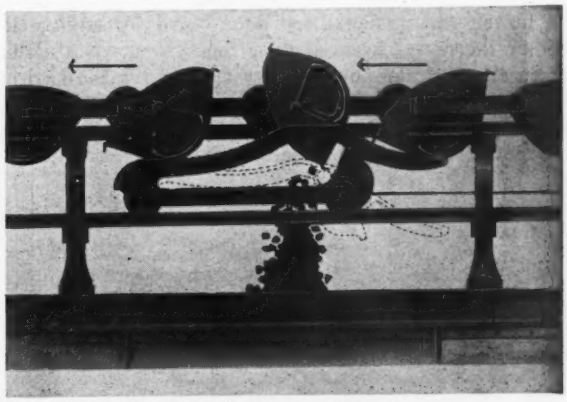


FIG. 10. MOVABLE TRIPPER USED WITH BUCKET CARRIER SYSTEM; SHOWING DUMPING ACTION

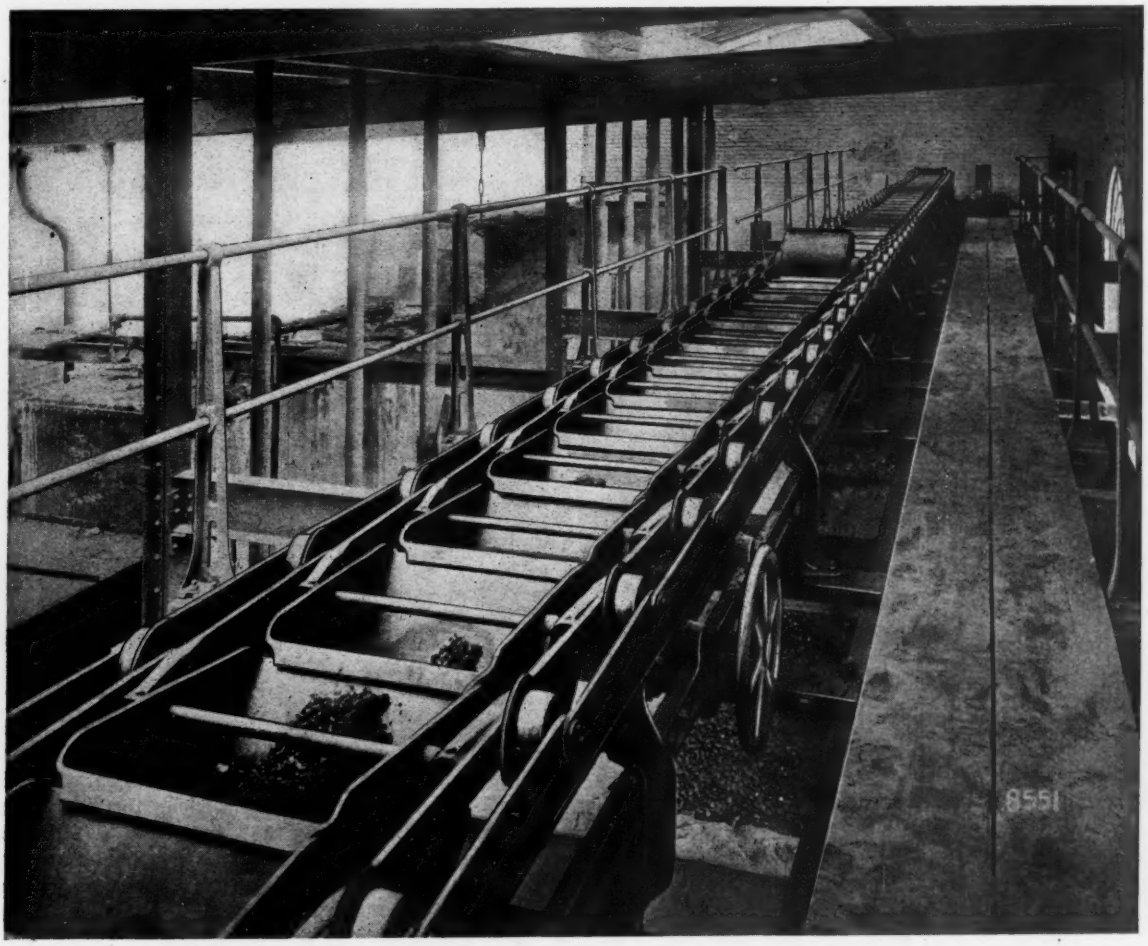


FIG. 9. PHOTOGRAPH OF THE UPPER RUN OF A BUCKET CARRIER INSTALLATION

The action of the reciprocating plate type is similar to the drum type in that the material is fed intermittently to the buckets as they pass under the filling hopper. A reciprocating plate actuated by an eccentric on a shaft geared to one of the roll shafts of the crusher allows sufficient coal to drop from the hopper to fill the bucket underneath.

The conveyor is generally driven through gearing by an electric motor at the top of the ascending run, as shown in Fig. 11. The capacity of a pivoted bucket carrier is dependent upon two conditions: first, the size of the buckets, and second, the speed of the carrier.

The size of the buckets, however, is the factor which

determines the capacity of the carrier. High speeds cause excessive power consumption and furthermore increase the wear on the equipment. Ordinary speeds are from 70 to 80 ft. per min., although fine coal may be conveyed at a higher rate of speed.

Power requirements are determined by adding together the power necessary for the system when acting as an elevator, the power necessary to carry the load on horizontal stretches, and the power required to operate the apparatus alone on horizontal stretches, including the power consumed by loading devices, etc.

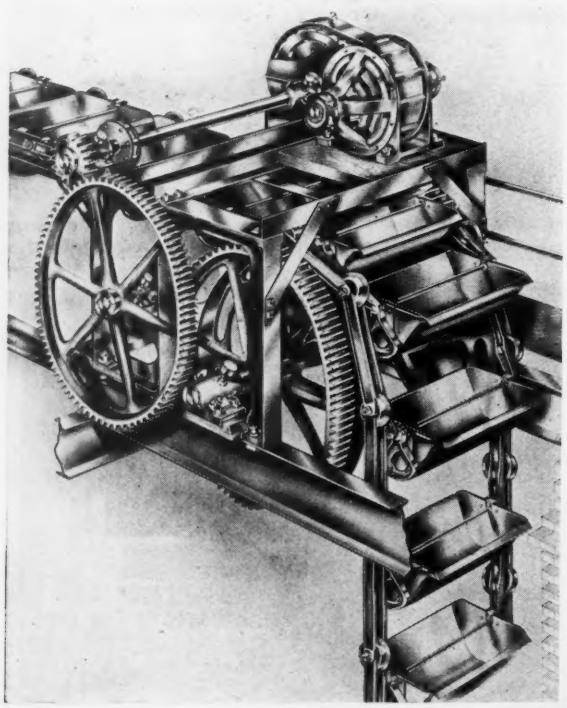


FIG. 11. SHOWING THE METHOD OF DRIVING A BUCKET CARRIER SYSTEM

Since the descending runs of the carrier counterbalance the ascending runs, the power consumed by the apparatus is practically limited to that required for the horizontal stretches. A reliable formula giving the horsepower required for a bucket system in which the variable factors are those of maximum load to be handled per hour, the distance through which the load is to be elevated and the horizontal travel of the buckets in one direction only, as follows:

$$Hp. = (0.7638\ WL + 1.5\ WH) \div 1000 \qquad (6)$$

where Hp. = horsepower required to operate the system.
W = capacity in tons per hr.
L = horizontal travel of buckets in one direction in ft.
H = height to which load is elevated.

The cost of bucket carrier systems will vary closely with their capacity in handling coal and in the average plant is dependent upon four conditions. First, size of the buckets; second, the total length of the carriers; third, the total length of the horizontal stretches; and fourth, the size of the carrier. The size of the driving machinery is dependent upon the last point, and it is, therefore, important.

On account of the numerous wearing parts, the maintenance costs of these carriers are comparatively high and frequent inspections are necessary in order to forestall serious breakages which are liable to occur.

The advantages may be summed up as follows: It combines ability to elevate and convey in a single machine; the material being carried and the buckets being supported by rollers, power is reduced to a minimum; the material may be discharged at any point, and the operation is comparatively silent.

Apron Conveyors

Similar in action but different in construction from the belt conveyor is the apron conveyor. This type is extensively used in conveying coal from a track hopper to a crusher a short distance away. In its simplest form, it consists of flat steel or wooden slats attached between two chains, forming a continuous platform or apron. It

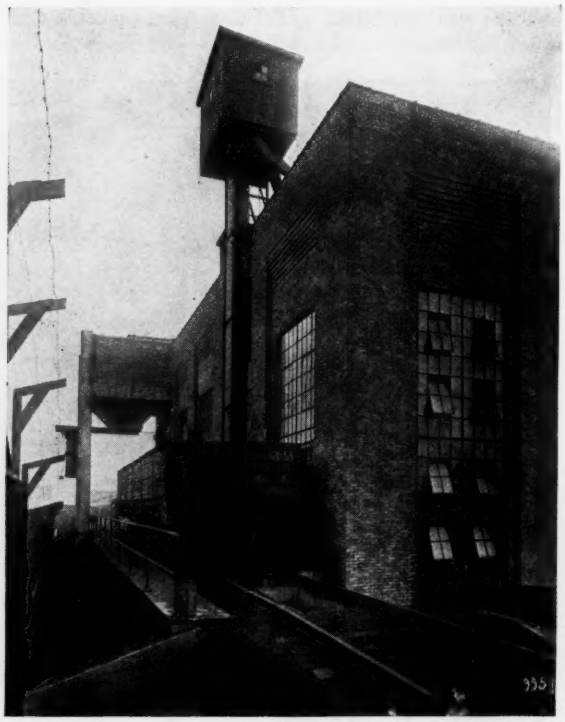


FIG. 12. VIEW OF A TYPICAL BUCKET ELEVATOR INSTALLATION

can be set at an incline and can be made of almost any desired length. The modern forms are equipped with side rollers which travel on rails along the sides of the conveyor, thus reducing the friction to a minimum. Since the load is actually carried, the power required to operate apron conveyors is less than with the flight type, but they are expensive to install.

End discharge only is possible and an inclination of 30 deg. is the practical limit with this type, unless the conveying elements are made in the form of bucket pans. When the angle of inclination is over 30 deg., however, the power requirements increase and it becomes an expensive elevating device. A typical installation is

shown in Fig. 6 where an apron conveyor is used to feed a bucket carrier.

The power requirements may be approximated by the use of empirical formula (1) given for flight conveyors, with a reduction of 10 per cent in the final figures. If the conveyor is composed of portions on different inclines, compute the power for each section separately and add 10 per cent for each change in direction.

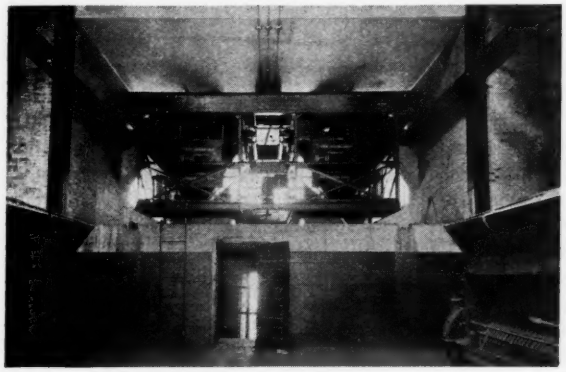


FIG. 13. AN ELECTRIC AUTOMATIC WEIGHING LARRY FOR DISTRIBUTING COAL TO STOKER MAGAZINES

Electric Weighing Larry and Hopper

THE METHOD of distributing coal from a large coal bunker located at one end of the boiler room to the stoker hoppers by means of an electric, automatic weighing larry possesses the distinct advantage of eliminating the necessity of overhead coal bins. This feature allows the construction of a skylight over the boiler room with consequent improved natural lighting conditions. This is an excellent method of handling coal in the boiler room and is in use in the more modern plants.

As shown in Fig. 13, the equipment consists of a larry suspended between two I-beams which run the length of the boiler room. The larry runs along the boiler fronts on these beams, in the manner of a traveling crane. It receives a load of coal from the bin at the end of the boiler room and an operator then distributes it to the individual stoker hoppers. The coal as it is taken into the larry hopper is weighed and the weight automatically recorded by means of a ticket punching device. A complete record of the coal used is thus assured.

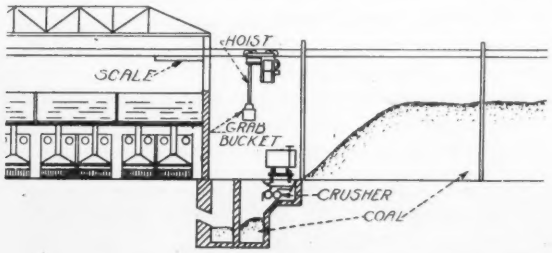


FIG. 14. DIAGRAM, SHOWING THE OPERATION OF THE TELPHERAGE SYSTEM

As shown in the photograph, this particular installation provides for delivering coal to boilers on each side of the fireroom aisle. The larry, however, is also made for installations with boilers on one side only, in which case it is fitted with only one distributing hopper.

The simplicity of this system together with its low maintenance costs and depreciation make it a desirable installation for medium size power plants. Of course, it is generally used in connection with some other type of conveyor, and this usually is a simple bucket type used to elevate coal into the bunker.

Another apparatus which resembles the electric larry just described is the traveling weighing hopper. This is used in plants with overhead bins. The weighing equipment is generally located between the overhead bin and the stoker hoppers so that coal can be drawn from the overhead bin and weighed before being delivered to the stokers. Ordinarily the overhead bins are located directly in front of the boilers and the weighing hopper runs on tracks below the bins. The balance of the beam scale is placed near the boiler room floor so that the operator can manipulate it. Weighing hoppers are usually equipped with motors geared to one of the axles to

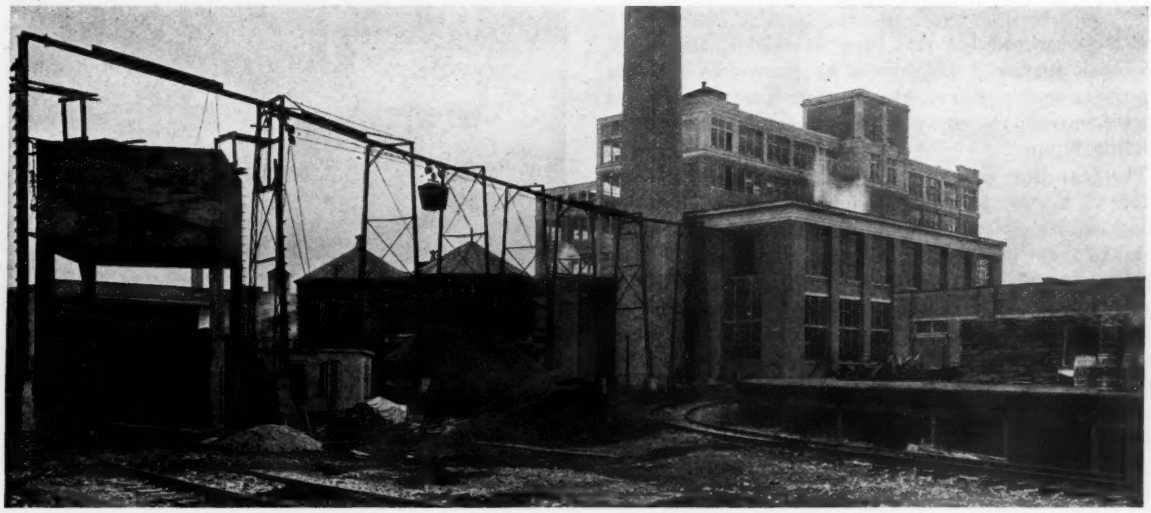


FIG. 15. TELPHERAGE SYSTEM INSTALLED AT A POWER PLANT

move it along the tracks, although when the load is light, hand-operated machines are provided.

Two methods are in use with regard to the manner of equipping a traveling weighing hopper with automatic scales. One is to place the automatic scale above and the receiving hopper below, so that the coal is weighed as it is drawn out of the overhead bins and before it is delivered to the receiving hopper. This is the best arrangement where it is desired to record only the total amount of coal consumed.

If an individual record of the coal consumption of each unit is required, the receiving hopper is placed above and the scale below, so that coal can be drawn

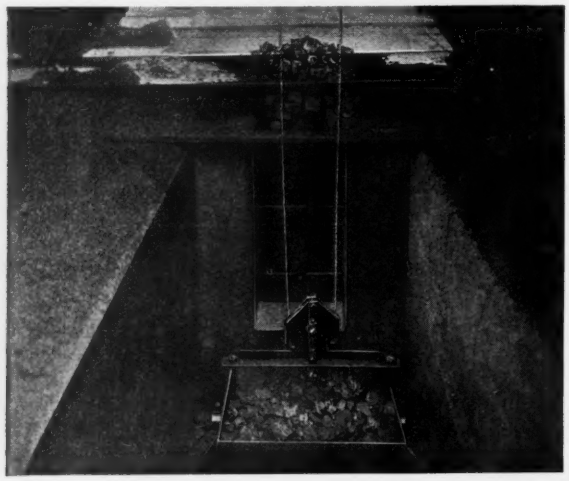


FIG. 16. METHOD OF FILLING BUCKET IN A PIT FITTED WITH GUIDE RAILS

from the overhead bin and then weighed by the automatic scale just as it is delivered to the stokers. In this case, the capacity of the stoker hopper must be sufficient to accommodate the amount of coal discharged by the traveling hopper.

The traveling weighing larry first described is to be preferred to the traveling weighing hopper, both on account of its greater simplicity and lower initial cost. With the traveling hopper and overhead bins, not only will the cost of construction and installation itself be greater, but in addition, a conveyor system of some kind must be provided above the overhead coal bins for filling them. They possess the advantage, however, of being able to do the work a little more rapidly, inasmuch as it is unnecessary to travel the length of the boiler room for each load of coal.

Hoists

Hoists are generally used in connection with some other equipment for the handling of coal in the power plant, such as the hoist and trolley, hoist and automatic railway, hoist and cable car, hoist and hand car, etc. The hoist and hand car and the hoist and cable car systems, however, are used but little and are not being installed in new plants to any great extent.

Hoist and Trolley: Telpherage

The telpher is a type of hoist which lifts and transfers the load on an overhead track system or monorail from one point to another. It is an excellent system and finds great favor in all sizes of plants and in many cases can be installed in an existing plant with less expense and fewer changes than could any other system.

A typical installation is shown in Fig. 14. Coal is removed from either the car or the pit by means of the clamshell bucket, and is transferred either to the coal storage pile or to the overhead bunkers in the boiler room. The operator's cage is part of the trolley carrier and all control is effected from that point. Such an installation will easily handle from 40 to 60 tons an hr., and the operating costs are exceptionally low.

All telpherage systems while similar in principle of operation differ in method of control, and in the method of filling and discharging the buckets. Figure 15 shows a telpherage system installed at a power plant employing a special type of bucket. The coal when emptied from the cars falls by gravity through a specially constructed steel chute into the 1-T. conveying bucket suspended on guide rails in a pit at the side of the track as shown in Fig. 16. When the bucket is filled, the hoist operator closes the gate in the chute, thereby shutting off the flow of coal into the bucket. The hoisting drum is then engaged, which raises the bucket to the required height and operation of the traction drum of the hoist moves the bucket along the conveyor track to the point where the operator wishes to dump the coal, either in the boiler room or at the storage pile. The bucket is next lowered until it comes in contact with the coal pile.

FIG. 17. INTERIOR VIEW OF BOILER ROOM OF THE PLANT SHOWN IN FIG. 15 SHOWING THE BUCKET ENTERING

The contact releases a latch on the bottom of the bucket, opening two doors, and the coal flows out without breakage. As the bucket is raised, it is emptied and the bottom closes automatically. Figure 17 shows the interior of the boiler room with the bucket entering. As shown in the photograph, coal is dumped on the floor and shoveled to the stoker hoppers. In most cases, however, the bucket empties into bunkers or weighing larries from which the stokers are fed by gravity. This installation is simple and is operated entirely by one man from one point. In case it is necessary to reclaim coal from flat bottom cars or open storage, the bucket described above may be changed to the clamshell type. Due to the fact that the hoist and operator do not travel on the mono-

rail with the load, a less expensive construction is needed than with the first type of telpherage system described.

The operation of these systems is not confined to a straight line, but can be made to include curves. The height of the track can be made to suit local conditions and storage requirements.

Instead of an overhead I-beam track, a cable may be used for supporting the bucket. The cable is stretched over two steel or wooden masts and the same principle of filling and hoisting is used as in the case of the I-beam construction. Where the carrier is required to deliver coal to the boiler room from a storage pile and must pass over a series of railroad tracks or other obstructions, the cable method may perhaps be the best as the monorail construction involves the use of structural work usually with concrete footings.

Where it is possible to operate the telpher without the addition of any other type of conveyor exceptional economies can be effected.

Portable Conveyors

Portable conveyors, of which there are numerous makes upon the market, possess distinct advantages in the field of coal handling machinery for the power plant. First, is their flexibility of application. They may be used under varying conditions and are adaptable for use almost anywhere in the plant. They are self-contained and in many cases are able to reach places which are entirely inaccessible to other types of conveyors.

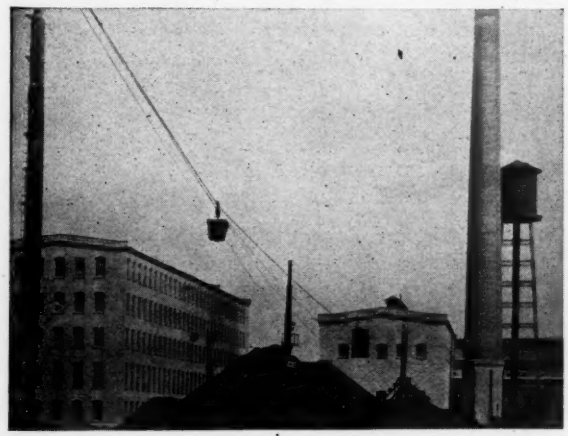


FIG. 18. TELPHERAGE SYSTEM USING A CABLE SUPPORT

These machines are made in the form of belt, apron or bucket conveyors, generally mounted upon a pair of wheels, although in some of the later types caterpillar tractors are used instead of wheels. For elevating at angles under 25 deg., a plain belt is employed. For angles of 30 to 35 deg., a belt equipped with steel flights is provided to prevent the material from slipping down the grade. A steel framework supports the conveying elements and is adjustable as to angle of inclination or the height of the discharge end. The smaller sizes are easily transported from place to place by one man.

Power is furnished by electric motor or a gasoline engine mounted directly on the frame of the machine. Where electric current is available, the electric motor for driving is recommended, both on account of its economical operation and its freedom from trouble.

The wide range of application and low cost of installation have served to make these machines popular in power plants. They may be used for loading and unloading trucks and cars, for handling coal for storage, for filling bunkers, for filling stoker hoppers in small plants not equipped with an overhead system of bins and for many other miscellaneous uses. Where coal is to be transported a comparatively long distance from car to boiler room, two or more units may be arranged in series, the discharge of one machine feeding the next one in line. In this same manner coal can be stored into piles from 30 to 40 ft. high.

In unloading bottom dump cars, all that is necessary is to shove the "nose" of a portable conveyor directly

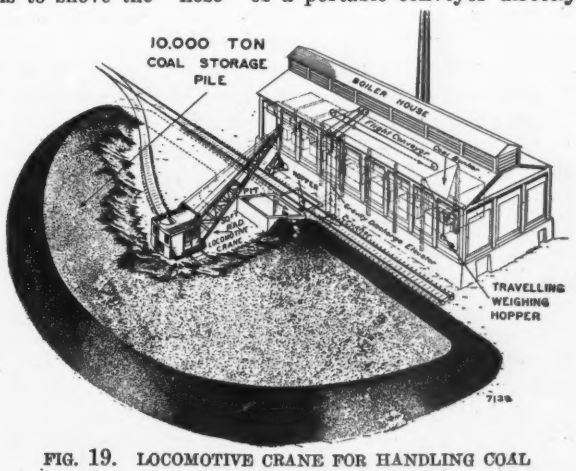


FIG. 19. LOCOMOTIVE CRANE FOR HANDLING COAL

under the hopper and to start the motor. If the belt or apron is kept filled, a car an hour may easily be unloaded in this manner, with only one man.

In small plants where it is inadvisable to install elaborate coal handling equipment, or where constructional alterations in the plant are anticipated, a number of these portable conveyors will very satisfactorily solve the coal handling problem.

Cranes

For handling coal in large quantities the locomotive crane occupies an important place in the field. Just as in the case of the portable conveyor, their adaptability to a wide range of service and conditions renders them extremely useful.

Figure 19 shows an outside reserve storage of 10,000 tons served by a locomotive crane traveling on a curved track. When the coal is unloaded from the railroad cars, it either goes through a crusher and up into the overhead bin in the boiler room, or into a pit alongside the track hopper, from which the clamshell bucket picks up and delivers it to the outside pile. When it is being reclaimed, it is handled from the pile back to the track hopper and up into the bin.

The average size bucket used on locomotive cranes for this purpose will hold about three tons and handling capacities as high as 240 tons per hr. have been obtained with them. In small or medium size plants, the locomotive crane offers a flexible method for handling and storage of coal and deserves consideration.

Another type of hoist, popular in large plants is the transfer hoist equipped with grab bucket. This is essen-

tially a monorail hoist operating on a traveling crane which gives it motion at right angles to the travel of the monorail system. The hoists can furthermore be arranged to travel from the cranes along I-beam spur tracks above the ground to the storage piles or into the boiler room. The operator in this case travels with the hoist and the load, and as a consequence a more or less expensive construction is necessary.

Overhead Bunkers

With a few exceptions practically all coal handling systems require the use of overhead bins in the boiler room for storing coal before being delivered to the stokers. These are constructed mostly of steel, and may be lined with a layer of concrete to protect the steel from the corrosive action of wet coal. This corrosive action, however, in most cases is not very serious and unlined steel bins have given good service for 15 yr. or more and are still in good condition.

Overhead bins may be supported, either by a structure of beams and girders underneath or, as in the later type suspension bins may be supported by rods or plates hung from girders along the top edges of the bin. This type takes proper advantage of the strength of the plates themselves and thus reduces the total weight of steel necessary.

Another type of suspended bin is made entirely of concrete reinforced with light steel plates. This bin is supported from girders in the same manner as the type described above, and has, in addition, a number of steel straps passing under the bin to serve as saddles or hangers to support the weight.

Both of the above described types of overhead bunkers are parabolic in form, so as to guide the fuel effectively to the discharge spouts and to prevent the formation of dead storage space. These later type bins are to be preferred to the older bins, because of their simplicity of construction and because of the absence of ponderous supporting structures. They present a neat appearance in the boiler room and on account of their more scientifically correct design are much lighter in weight than the old type bunkers.

The methods described in the foregoing are the principal ones for handling coal in power plants at the present time. There are other systems in use, but such systems are the exception rather than the rule, and until their use becomes more common, cannot be considered as common practice. As an example, the vacuum system for handling coal is in use in one or two plants. Because of these few installations, however, the vacuum system as a means of conveying coal cannot be considered as a commercially successful system. As this system is in more or less common use for the handling of ashes, it is more fitting to list it under that heading. The same is true of the skip hoist; this is also much more common as a means of handling ashes in power plants than for coal.

Each of the systems described has its individual advantages and disadvantages and as stated at the beginning of this article, before determining upon any system, a careful study of plant conditions and costs must be made. The savings effected by any system will vary with the size of the plant and may be anything from a fraction of a cent to 4 to 5 cents per ton of material handled.

Coal Storage

Insurance Against Shutdowns, Proper Location of Pile, Methods of piling and Reclaiming, Fire Hazards

In the operation of a power plant, the one all important raw material is the fuel used in the furnaces, and this material must come to the boiler room as it is needed or the plant will fail to perform its duty as it should; it is therefore essential that there be no failure to deliver the required fuel in quantities that are easily handled by the firemen. Continuity of service is essential in nearly all power plants and the owners will go to great expense to provide the plant with standby units to be used in case one of the main units fails for any cause, yet it is not at all uncommon to find a plant where the coal supply kept on hand will not run the plant for more than two days. That more plants have not been shut down for lack of fuel, speaks well for the system of coal delivered which serves the plants of the country.

During the past few years, however, the uncertainty of obtaining fuel when it is needed has made it imperative that some means of keeping a supply on hand, for emergencies at least, be provided. Not only will the storage of coal insure the needed supply, but if stored at the proper time the purchaser will usually get the advantage of the lowest price of the year, which is often quite an item in the operation of a power plant.

Store in Summer

Storing coal in summer is of advantage to the railroads in that it will tend to equalize the freight traffic throughout the year, as that of the late spring and summer months is usually light, and considering that for some time the limit of coal production has been governed by the supply of cars for transportation, this becomes a big factor. By no means the least advantage of storing coal in summer is the influence it will have upon the production of coal the year around. With steady employment for the miners, the necessity of recruiting an entirely new force every fall when the mining season usually opens up or of holding many men on short time during the summer would be done away with and a trained and efficient organization would be always at work, of which the advantage to industry in general cannot be disputed.

As intimated above, the time to store coal in this country, is between the first of May and the first of September; during this period not only are the prices lowest, freight traffic lightest and the coal production at the minimum for the year, but the weather is usually dry, the coal does not need to be thawed out before dumping from the cars and the necessary work in the yard can be done with the least discomfort to those who do the storing.

Until recent years, it was the general belief that only coals with low volatile combustible content and free from to keep close watch of it to see that it does not heat and

sulphur could be stored with safety, but investigations have been made which show that all kinds of coal have been stored without catching fire; on the other hand, there is no kind of coal that has not given trouble when stored under conditions favorable for spontaneous combustion. It would appear from investigations that the condition of the coal as regards size has greater influence on liability of firing than does the chemical analysis, nevertheless it has been found inadvisable to store coals from different mines in the same pile, as they appear to heat more at the place where they come together than where coal from one mine only is located.

Sizes to Store

Best results are secured with large lumps of sized coal; run-of-mine coal is unsafe for storage, as in the piling there is a tendency for the fine coal to separate and the coarse coal to form air pockets which supply the smouldering coal with the oxygen needed for combustion. Slack and fine coal have a tendency to heat and must be watched with extreme care; the only really safe way to store this kind of coal is under water where no air whatever can reach it. There is a common belief among engineers that coal with a high percentage of sulphur will give trouble with heating. The results of investigations seem to show that the reason for poor results with this kind of coal is because the sulphur causes the coal to break up into fine coal and the fine coal causes the heating. It is apparently the oxidation of the iron pyrites that causes the breaking up and this is aided by the alternate wetting and drying of the coal while it is in storge.

Choice of Location for Storage Pile

If coal is to be stored safely and economically, the choice of the location for the pile or bin must have first

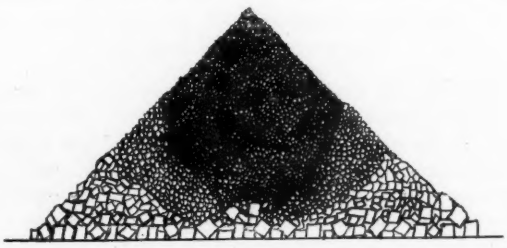


Fig. 1. Cross section of conical coal pile, showing natural separation of sizes of coal when coal is dumped at the center continuously

consideration. Industrial plants sometimes find that provision can be made in the basement for storing all the fuel that is necessary to run them over any period of coal shortage. This location has the advantage of being dry so that the coal is not exposed to the rains and snow which affect to a slight extent the value of stored coal; with proper arrangement, the coal may be dumped into the storage bin directly from trucks, thus eliminating the necessity of rehandling; the location should be conveniently located as regards the boiler room so that machinery for mechanical handling can be installed or, if the coal is to be wheeled to the boiler room in cars or barrows, the basement bin is about the most handy location for storage; when coal is in storage, it is necessary with basement storage this can readily be done by the engineer in his daily rounds; in case it does heat, the coal is not readily moved to cool it down, but with proper provision the entire bin can be flooded in case a fire breaks out.

This location for storage is, however, expensive in that the space can usually be used for some other purpose that will pay higher interest on the investment; also the space is nearly always limited and in most cases will be found to be inadequate; the increased fire hazard to the building and the danger which may result from the formation of gas in case the coal heats must not be overlooked when deciding upon the basement as the location for coal storage.

By far the most common and in many ways the best location for the coal storage is in the yard adjacent to the power plant. The space, of course, is not always available, but when it is the rental expense is much less

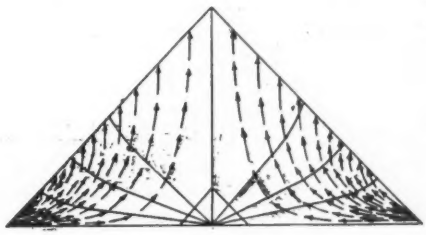


Fig. 2. Course of air currents through conical pile of coal formed in fig. 1.

than for basement storage. This location permits the use of almost any method of piling and reclaiming that is in use today, thus giving the advantage of a complete mechanical system for handling the coal from the cars to the furnaces, if the size of the plant warrants the investment. With an open space of this sort, arrangements can readily be made for rehandling in case the coal shows signs of serious heating and in case fire does break out it can be handled so as to be of no danger to the plant or surrounding buildings.

Open storage in yards is more common than storage in sheds, due principally to the added expense of the latter. The value of dry storage lies in preventing the coal from alternate wetting and drying due to rains and snows which, with coals containing sulphur, causes it to crumble, which, in turn, increases the fire hazard. Dry storage in winter is of advantage in that it prevents the freezing of the coal with consequent difficulty in handling. On the other hand, sheds are an expense not always warranted; they offer an additional fire hazard, particularly if of wood, and in case of fire the shed structure is usually a handicap in rehandling.

The yard location usually offers a good opportunity for employing underwater storage, for the coal must be handled mechanically by means of grab buckets when reclaiming which can be made part of the plant equipment. Water may be taken from a stream or lake if the plant is fortunately located in that respect, or rain water from various buildings may be piped to the storage pit at little expense. The smallest sizes and cheapest grades of coal can be stored in these pits with perfect safety from fire and the presence of the coal would not be a menace to surrounding buildings. The pits are some-

what expensive as compared to ground storage, for they must be waterproof and are usually of concrete sometimes with plank sides. Ice in winter is frequently a deciding factor against water storage and coal dripping with water is not in the best condition to feed to boiler furnaces.

For plants located in restricted districts, about the only place that coal can be stored in quantities is in some outlying yard near the railroad. Here the coal may be

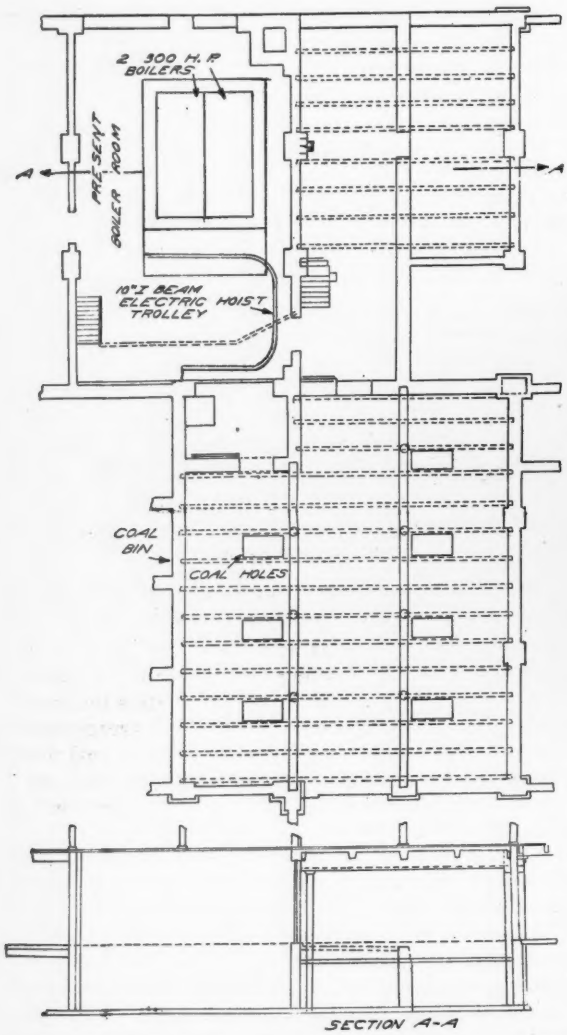


FIG. 3. PLAN OF A CONVENIENTLY ARRANGED BASEMENT STORAGE BIN. REINFORCED CONCRETE ROOF AFFORDS LOADING RUNWAY FOR TRUCKS

dumped direct from railroad cars or piled in other ways which will be described later. The rental expense for such storage space is low and with modern methods of piling there should be no demurrage charges on cars. The cost of reclaiming and delivering coal to the plant will be higher with this location of the storage pile than with any of the others mentioned, as the coal must be reloaded into trucks or cars for a long or short haul to the plant, there to go through whatever system may have been provided. When stored so far from the plant, it is not convenient for the engineer to keep close watch of the piles in regard to heating and serious losses are sometimes experienced that could have been averted had the condition of the coal piles been known in time.

Power plants for office buildings, small factories and the like that do not require a great amount of coal have found it profitable in some cities to co-operate in the storage of coal by renting space in an outlying district near railway tracks and storing the coal as a co-operative enterprise. Advantage is thus taken of any reduction in price due to large shipments, so that the small plant has the same economic advantage as the large plant that is compelled to store its coal at a distance from the plant.

Deterioration and Fire Hazards

According to tests made by the U. S. Bureau of Mines, the loss in heat value during storage is practically negligible as will be noted from Table I shown on page 22. As might be expected, the smaller sizes of coal showed greater deterioration than larger sizes of the same quality, but the only coal tested which showed any appreciable deterioration was the subbituminous. Tests made by the Engineering Experiment Station of the University of Illinois on coal from various parts of the state of Illinois showed that the deterioration during one year of dry storage varies from 3 to 3½ per cent, while with underwater storage no deterioration whatever is experienced.

FIG. 4. PORTABLE CONVEYOR USED FOR UNLOADING COAL CAR WITHOUT TRACK PIT

The greatest losses sustained in the storage of coal is due to fires caused by internal combustion and every known precaution should be taken to prevent such fires as no coal is immune, and once started a coal fire is extremely difficult to extinguish. Coal coming fresh from the mines is very active chemically, some of its constituents having a strong affinity for oxygen even at ordinary temperatures. This quality, of course, varies with the constituents of the coal and increases with the superficial areas of the particles of coal, i. e., the finer the particles of coal the more active is the chemical affinity of the coal for oxygen.

In the storing of coal, the methods of piling must be such as to carry off the heat caused by this chemical union or to prevent all air from filtering through the coal pile. The time of greatest danger from fires in coal

piles is six to eight weeks after storage and some engineers recommend rehandling the coal about this time in order to cool it off; but more modern practice seems to favor careful and diligent inspection of the coal for heat during the first three months, and rehandling only that portion which may have become heated.

In most cases of heating, the hot spots seem to occur from 5 to 8 ft. from the exposed surface of the pile and various authorities recommend 12 to 15 ft. as the maximum depth of the storage pile for safety. From various investigations, it would appear that the fire hazard is independent of whether the pile is under cover or in open space.

Mixed sizes of coal are most difficult to store in piles.

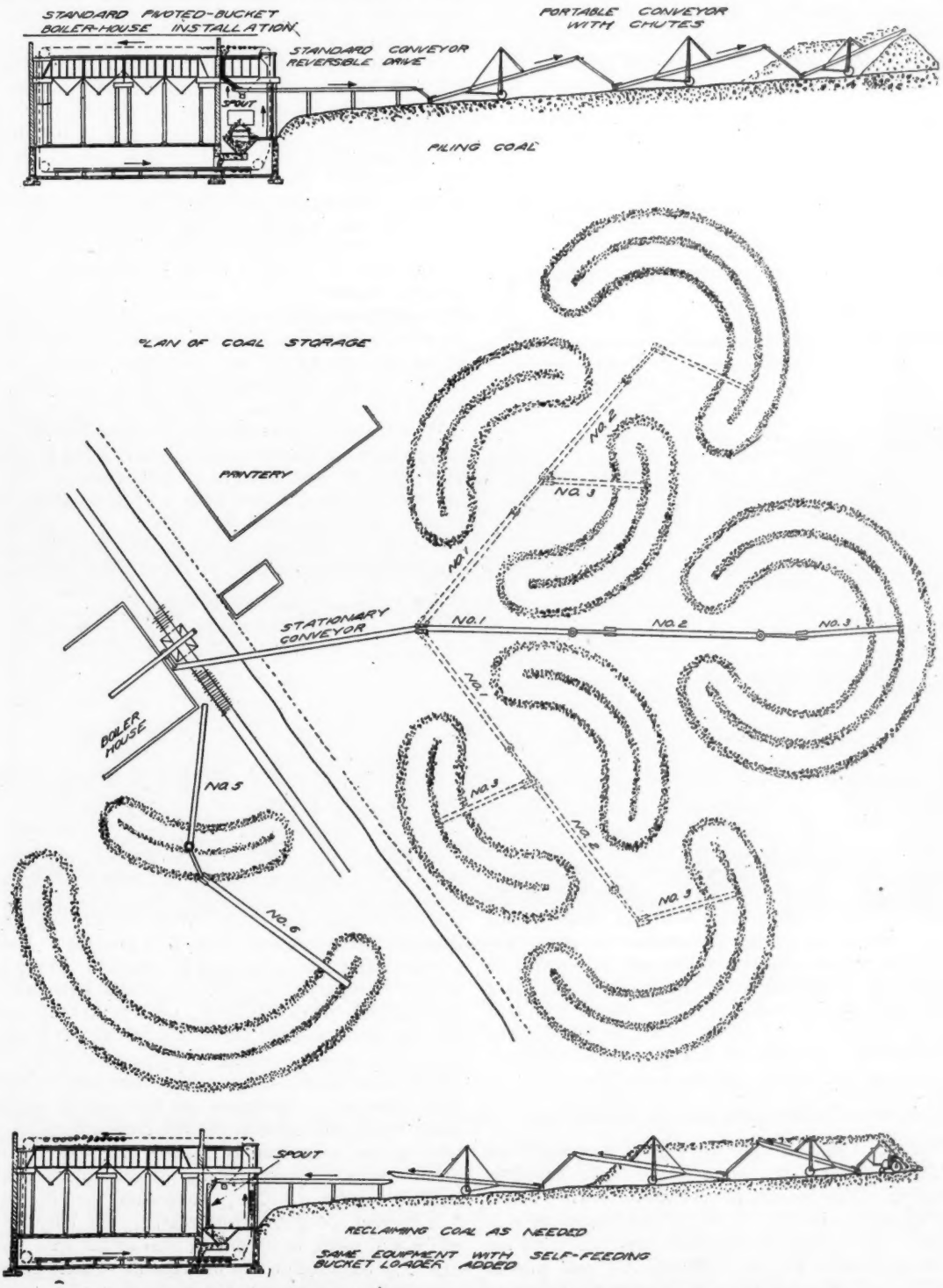


FIG. 5. PLAN OF STORAGE PILES AT PLANT EMPLOYING PORTABLE CONVEYORS

The reason given for this is that the fine particles separate out from the lumps in the piling process and thus spaces are formed in which air circulates locally and supplies the oxygen necessary for starting a fire, but not enough of the warm air and gases are carried away to keep the coal from rising in temperature to a dangerous point.

Among the causes that contribute towards the burning of coal piles are hot walls, chimneys, steam pipes or any other surface against which the coal may be piled whose temperature is above that of the atmosphere. Re-

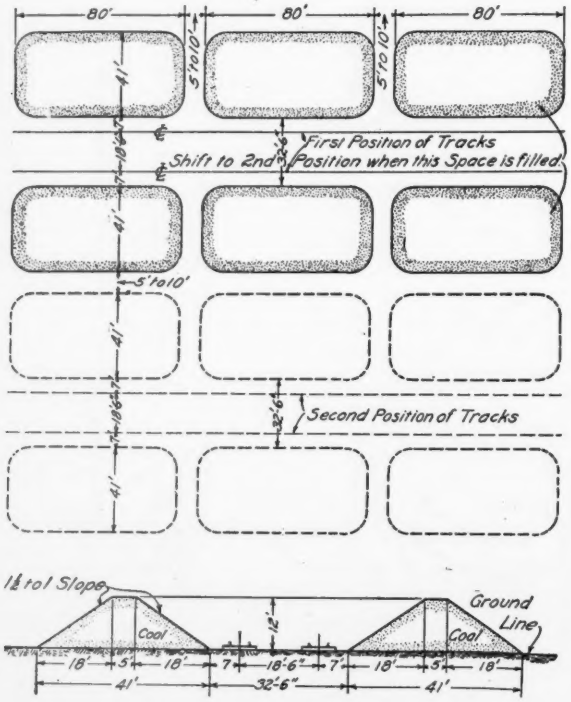


FIG. 6. PLAN OF COAL YARD WITH PARALLEL TRACKS

fuse of many kinds, such as rags, waste, paper, excelsior, are frequently the starting causes for fires to coal piles. Chunks of wood, wooden beams, braces, pillars are also sources of danger, as their temperature of ignition is lower than that of coal and frequently they cause passages which give the air necessary for combustion but not sufficient to keep the temperature below the danger point.

In all cases of coal storage the temperature at various points of the pile should be watched carefully and if it reaches as high as 140 deg. at any point this should serve as a warning. If it increases to 150 or 160 deg. the coal should be moved and spread out to cool or fed directly to the boiler furnace. At 180 deg. bituminous coal will begin smoking and firing is an imminent danger.

Reducing Temperature and Fighting Fire

If all parts of a coal pile are kept at a temperature below 150 to 160 deg., the danger of fire is eliminated, so the problem of safe storage of coal is solved when a system of storing is devised by which the temperature is kept low. It is generally conceded that either no air must be allowed to circulate through the coal pile to supply the oxygen necessary for the chemical action or there must be a sufficient circulation of air to carry off the heat of oxidation at low temperatures as fast as it is generated.

The latter theory has led to the use of various ventilating schemes, but to date no authority seems ready to recommend any scheme as reasonably safe, though in Canada, where temperatures are considerably lower than in the United States, the railroad companies are using ventilating ducts in their storage piles with success in preventing fires.

The other method, i. e., preventing air circulation in the coal pile, is the one which is almost universally adopted in this latitude. The variables are so many, however, that in addition to extreme care in piling the coal diligent inspection of all parts of the pile is essential for at least the first three months after the coal is stored. Once a spot is found that has a temperature above 150 deg. it should be dug out and exposed to the air until its temperature has reached that of the atmosphere before it is again stored permanently. It may even be necessary to move the coal several times before it reaches a temperature that is safe. Heated coal that has been taken from a pile should be separated from the rest of the pile and spread out rather thin over the ground in an airy place and away from buildings where, if it should break into flames, it will not endanger property.

Hot spots in a coal pile must be handled with extreme care as once air reaches the coal it may burst into flames which spread very rapidly. When removing coal that has become heated, a good supply of water should be at hand to be used in case flame does start. For fighting a coal pile fire, however, water must be used with discretion and then only as a last resort when handling the

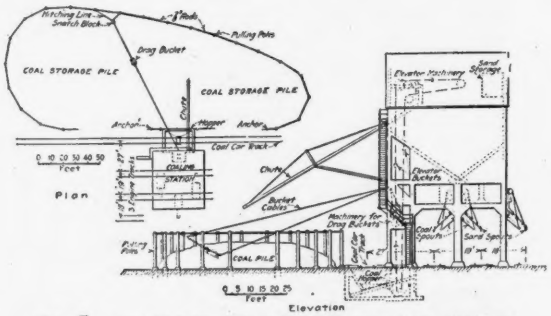


FIG. 7. DRAGLINE AND BUCKET STORAGE SYSTEM

coal has become impossible. Water to put out a fire of this sort is of value only when it is possible to flood the affected part; surface wetting is a failure. When it has become necessary to use water, a method recommended by good authorities is to dig a pit 2 ft. deep around the hot spot, make holes in the bottom of this pit to the bottom of the pile by driving a pointed rod at short distances apart and pulling it out; then keeping this pit filled with water surrounds the fire with a curtain of water which will prevent the fire from spreading. The burning coal may then be soaked with water to extinguish the fire. Merely wetting the hot and burning coal is likely to form a wall of coke around the affected part and prevent the water from reaching the burning coals which will again break out as soon as the coke becomes dry. Carbon dioxide and bicarbonate of soda have been used as fire extinguishers but have not in all cases proved successful.

Methods of Piling

Before going into the detailed descriptions of the various methods of piling now in use, some general rules will be given by which each available system should be measured before it is adopted.

Arrange the coal pile so that any part can be removed readily.

Provide a means for free circulation of air throughout the entire coal pile or prevent entirely the circulation of air through any part of the pile.

In piling mixed sizes of coal, when such is necessary, the method must avoid separating the sizes into layers; piling in horizontal layers is preferable to cone-shaped piles as the coarse coal in the latter case rolls to the outside of the pile while the fine coal is at the center of the pile forming the core where air circulation is restricted but not entirely eliminated due to the spaces around the larger lumps.

The depth of the pile should not be more than 12 to 15 ft.

Trim the pile so that no part is more than 10 ft. from the surface.

Locate the pile on dry ground or an airtight floor.

Storing coal by the hand method consists in wheeling it from the cars in which it is shipped to the coal pile by means of barrows. First a layer of coal is dumped out on the ground, one load against another until the entire area which the pile is to occupy has been covered. When this layer has been leveled off on top, another layer is wheeled on top and spread out in the same way, using planks to walk on. This process is continued until the pile reaches the desired height. By this method, the coal is practically laid in the pile, there is no chance for the fine coal to separate out and the breakage is a minimum. Coal stored in this way should keep, if it can be stored at all, but the method is very expensive and in case the coal must be moved quickly on account of heating the hand method must be depended upon, which is not only comparatively slow but most disagreeable.

A more convenient method of storing is by means of auto trucks or wagons. The same system of piling the coal in layers may be adopted with trucks as with wheelbarrows by laying a platform on the first and succeeding layers when placing the courses on top. For this work, side dump trucks are the most convenient, as the coal can be discharged alongside the platform in a row and the platform moved sidewise when the space on one side has been covered. With this system, leveling is easily done and the method is not one that has a tendency to break up the coal. This method is particularly applicable when the coal must be carried for some distance from the railroad to the place of storage, as no other mechanical means for unloading the coal need be provided. Storage by trucks is also recommended for the reason that driving over the pile with the heavy loads packs the coal solid and prevents the formation of air passages.

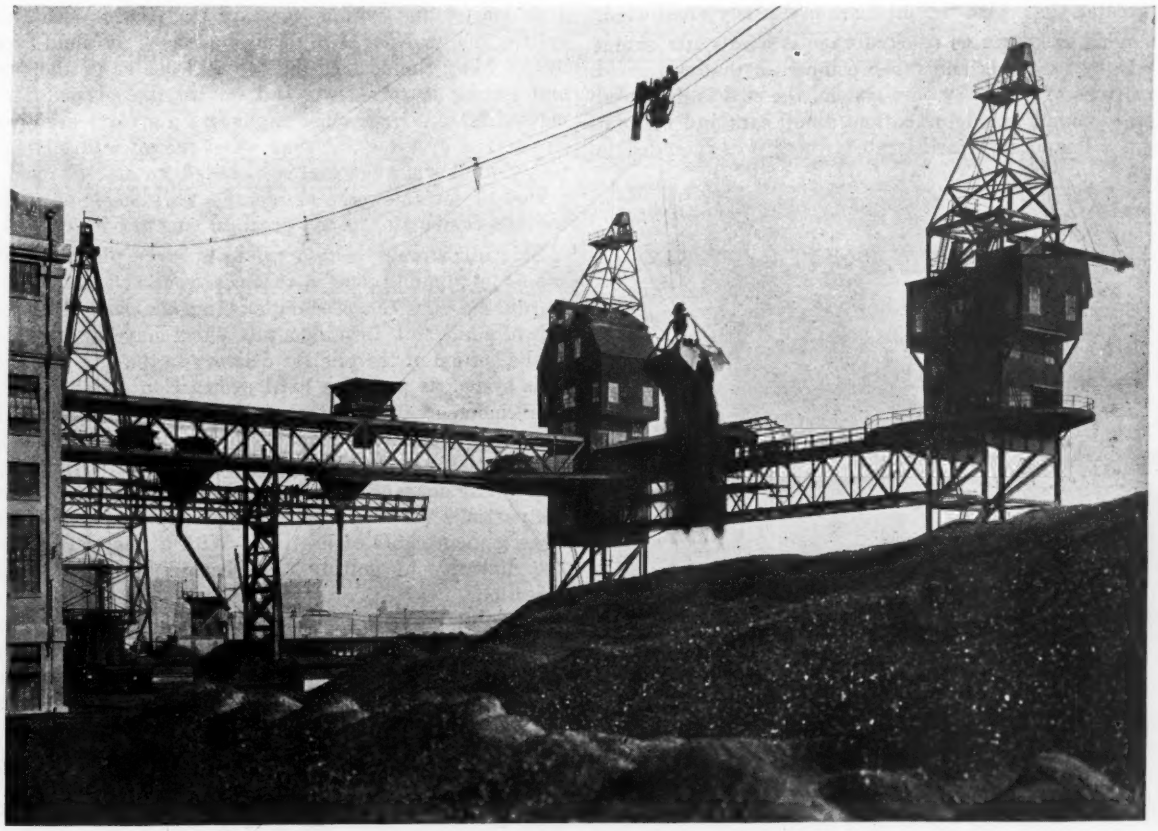


FIG. 8. TOWERS WITH CABLE AND BUCKET FOR STORING COAL

For storing coal near the railroad track upon which it is delivered, a wagon loader discharging to a series of portable conveyors has met with success in many plants

and is one of the most inexpensive employed. When these means are used, however, the tendency is to form cone-shaped piles the core of which is composed mostly of the fine coal surrounded by coarse coal which permits the filtering of air through the pile to the center where the heating, if any, is likely to occur.

To overcome this difficulty, it is necessary to move the discharging conveyor frequently or to arrange a chute at the end so as to give, in effect, layers of coal made up of small piles rather than one big pile made from one setting of the conveyor. The most convenient shape of pile with this type of apparatus is in the form of a circle which does not necessitate the frequent moving of the conveyor. Coal piled by this means is likely to be broken more than by the hand or truck methods and falls loosely in the pile so that the liability to heating is greater than with the methods previously mentioned.

What is known as track storage is used quite extensively by railroads and other companies that use great quantities of coal. By this system, the coal is delivered to the ground in side or bottom dump cars and run out upon a temporary track located where it is intended to

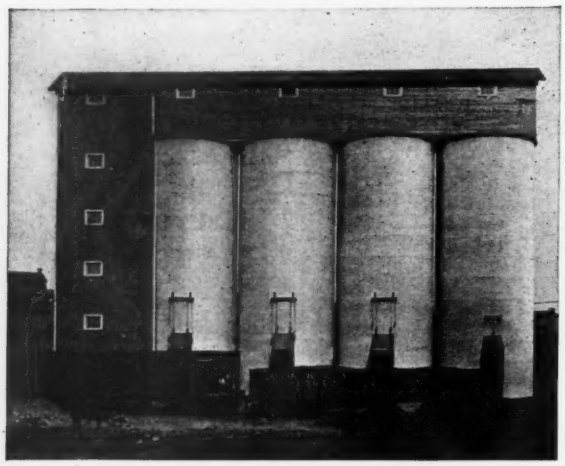


FIG. 9. SILOS FOR COAL STORAGE

make the pile. Here the coal is dumped as high on both sides of the track as possible, then on the track itself, the track is then pulled up through the coal by means of some sort of crane and another layer piled on top of that already formed and the process continued until the pile has reached the desired height. Then the track is dragged sidewise and the coal dumped on the side of the pile to roll down at the edge. A ballast spreader is sometimes used to level off the coal and prepare a place for the track.

This method has a tendency to break the coal badly and causes stratification of the different sizes, thus giving the same hazardous condition as the pyramid pile. Hot spots in piles formed in this way are not easily removed with the means usually available which makes the hazard great and with this method of piling it is not easy to separate the coal into long piles, which would limit the fire hazard.

Another method of storing in piles is employed at many plants where the coal is delivered in railroad cars on switch tracks. In this system, parallel tracks are laid in pairs of two in the storage yard with space between the pairs for the coal piles. The coal, possibly several carloads, coming to the plant is switched on to one of the tracks; a locomotive crane with grab bucket is run on the track beside the loaded cars and unloads the coal to the pile in the space between the pairs of tracks. When this equipment is used, the method known as spread piling should be employed. This consists in dumping the bucket so that each load is practically laid in its place without rolling or sliding, thus the pile is built up in layers similar to hand or truck storage with the exception that the work is done mechanically and the coal is not packed so solid. To prevent breakage of the lumps, the bucket should be lowered close to the coal already piled. For starting the piles, side dump cars can be used to a certain extent, but when necessary to use the grab bucket, flat bottom cars are essential. With this system, the tendency is to form piles of the pyramid type by dumping the coal at the top and center of the pile and letting it roll down and out to the edges. This method is, of course, more rapid and a greater area can be covered by the crane than when spread piling is employed; but when the coal is intended for storage over a period of several weeks or months, the danger of spontaneous combustion is too great to warrant its use.

Side hill storage is resorted to at some plants which are so fortunately located that coal coming to the plant in railroad cars can be dumped from the cars down the side of a hill, thus forming a pile which may be reclaimed at the bottom of the pile for delivery to the power plant. This system is purely a local proposition and has little to recommend it except that it is inexpensive both in first cost and in labor for storing. The objections to its adoption are that dumping from the cars, tumbling and rolling down the hill breaks the coal badly and causes the partial separation of the different sizes of coal which is a frequent cause of heating. With a pile of this sort the difficulty of getting at a heated spot is a great objection.

One of the most common methods of storing coal at power plants and from the standpoint of fire hazard the last to be recommended is that known as trestle storage. With this system, an elevated track is built over the storage yard and from this the coal is dumped in a pile beneath. The track may be built to accommodate railroad cars, mine or industrial cars drawn by electric locomotives or cables, monorail buckets or a platform with trapdoors upon which trucks or wagons may be drawn.

The one advantage of this system is the ease with which the coal may be dumped. On the other hand, the trestle is expensive to build and when used for storage alone or for storage and reclaiming stored coal the track will be idle a great share of the time, making the overhead expense great. To offset this expense, however, many plants use these trestles in the handling of their daily coal deliveries. Piles formed from trestles take the form of pyramids with all the fire hazards encountered in this form of coal pile with the addition that the coal is badly broken in falling to the pile and that the trestle legs frequently form air passages that are the starting points for fires.

Coal stored under trestles is not easily reclaimed without other special provision and in case of a fire great

losses may by sustained due to this difficulty in removing hot coal quickly. One method of reclaiming is by means of a locomotive crane and grab bucket, but difficulty in reaching all parts of the pile are met because of the interference of the trestle legs and braces.

accomplished by means of the bridge and grab bucket which may be used to deliver the coal to the coal handling equipment of the power plant or to a part of the storage yard where it may be spread out and cooled before returning to the storage pile.

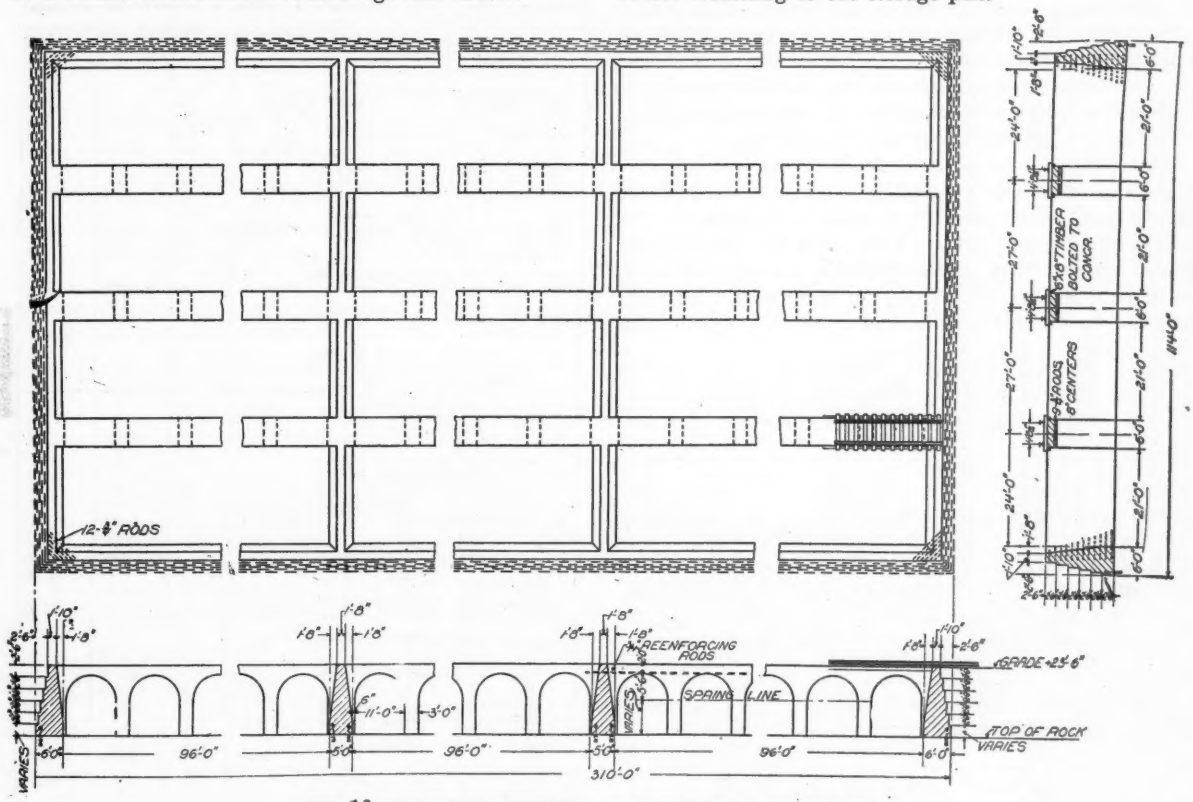


FIG. 10. PLAN AND ELEVATION OF UNDERWATER STORAGE PIT

The bridge crane and bucket method of handling and storing coal, though expensive, offers many advantages where the storage pile can be located in the yard near the power plant and railroad cars take the coal direct to the yard. The bridge, of course, should cover the entire storage space and the track. With this equipment, coal is taken from the cars and by means of spread pil-

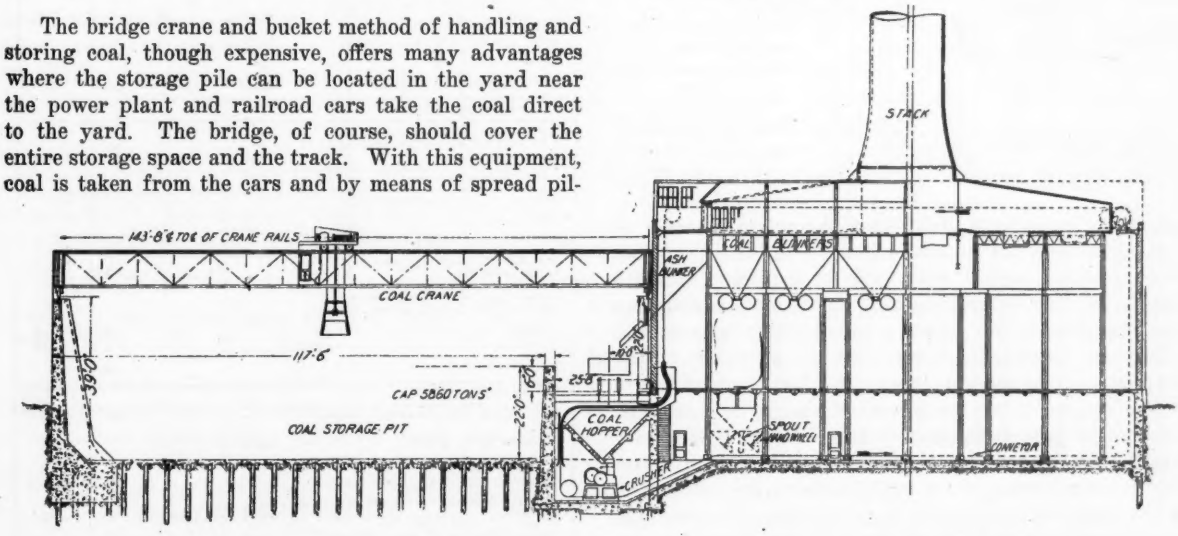


FIG. 11. ELEVATION OF UNDERWATER STORAGE PIT AND POWER PLANT COAL HANDLING SYSTEM

ing in layers with the bucket lowered close to the pile when dumping breakage is reduced to a minimum and all precautions in regard to stratification of different sizes of coal can be observed. Reclaiming of any part of the coal pile which may have become heated is readily

Piling coal by means of a dragline and bucket is a comparatively cheap method of storing coal over a limited area. The great disadvantage is that there is a tendency to form pyramid shape piles which are subject to heating due to the difficulty of shifting the cable to a

new position. There are modifications of this system which have advantages almost as great as those of the bridge crane and bucket. In one of these, the receiving end of the cable way is held stationary, but the outer end is attached to a tower mounted on wheels and run on a circular track, thus giving a sweep over a considerable area and an opportunity to use the spread method of storing. In the other method, both ends of the cableway are mounted on wheels and run on parallel tracks; by this means, a larger area can be covered with the other advantages of spread piling and reclaiming.

Among the more recent methods used in storing coal is the use of silos or vertical cylindrical tanks made of planks or in some cases of reinforced concrete or even steel. This type of storage tank takes up little ground space; several tanks may be built in a battery so as to hold from 100 to 1000 tons; the coal is handled completely by mechanical means and in case any part of the coal shows indications of heating, the entire contents of the tank may be run out on the ground and cooled or that which is cool may be run back in the tank and the heated coal only separated out from the mass and spread out for cooling. If, however, severe heating has occurred before the condition has come to the attention of the attendant, provisions are made for flooding the entire tank, thus securing the effect of underwater storage. Among the principal disadvantages of the system are that the coal is usually broken up considerably in dropping it from the top of the tank to the surface of the coal in the tank, when any coal is drawn from the tank the whole mass is moved, which has a tendency to form air pockets and break the coal, and the installation cost is considerable in comparison with other systems.

The only system of storing coal which has met with universal success in the matter of preventing fires is to store it under water. Tests have shown that there is no deterioration whatever in heat value and where salt water is used, an actual gain in heat value has been noted. Any kind of coal can be stored under water with perfect safety, nor does the method of piling, or the mixing of sizes or kinds of coal give trouble from heating. The tanks, however, which are usually constructed of concrete, are rather expensive and the method of reclaiming is limited to the use of grab buckets. Storing is usually done with a locomotive crane or from low

TABLE I. CALORIFIC VALUE (IN GRAM CALORIES) OF THE COAL SUBSTANCE (MOISTURE, ASH AND SULPHUR FREE) BEFORE AND AFTER STORAGE

Kind of coal.	Storage conditions.	Place.	Calorific value. As stored.	After 3 months.	After 1 year.	After 2 years.	Per centage of loss in 2 years.
New River, W.Va.[a]	¼-inch coal, under sea water.	Portsmouth, N. H..	8,761	.....	8,759	8,730	[b]0.39
		Norfolk, Va.....	8,754	.....	8,753	8,737	[b].49
		Key West, Fla.....	8,747	.....	8,747	8,770	0
	¼-inch coal, under fresh water.	Pittsburgh, Pa.....	8,752	8,762	8,749	8,760	0
	¼-inch coal, exposed to air indoors.	Portsmouth, N. H..	8,779	8,738	8,742	8,709	.80
		Norfolk, Va.....	8,751	8,742	8,736	8,717	.39
		Key West, Fla.....	8,754	8,728	8,676	.....	.....
		Pittsburgh, Pa.....	8,769	8,736	8,719	8,720	.56
	R. o. m. coal, exposed to air indoors.	Portsmouth, N. H..	8,754	8,758	8,748	8,734	.23
		Norfolk, Va.....	8,743	8,764	8,725	8,725	.21
		Key West, Fla.....	8,745	8,733	8,710	.....	.....
		Pittsburgh, Pa.....	8,753	8,758	8,740	8,743	.11
	¼-inch coal, exposed to air outdoors, uncovered.	Portsmouth, N. H..	8,741	8,730	8,701	8,674	.77
		Norfolk, Va.....	8,726	8,709	8,666	8,625	1.16
		Key West, Fla.....	8,739	8,721	8,680	8,592	1.85
		Pittsburgh, Pa.....	8,763	8,726	8,700	8,665	1.12
	R. o. m. coal, exposed to air outdoors, uncovered.	Portsmouth, N. H..	8,775	8,766	8,760	8,723	.60
		Norfolk, Va.....	8,743	8,745	8,720	8,695	.55
		Key West, Fla.....	8,752	8,708	8,722	8,632	1.29
		Pittsburgh, Pa.....	8,752	8,740	8,716	8,696	.64
Pocahontas, Va.....	120-ton pile, r. o. m. coal, outdoors.	Panama.....	8,794	8,787	8,762	.....	.....
Pittsburg bed.....	4 tons r. o. m. coal in open bin, outdoors.	Ann Arbor, Mich....	8,541	[c]8,539	8,526	.....	.....
			8,541	[d]8,553	8,528	.....	.....
Sheridan, Wyo., subbituminous.[e]	R. o. m., open bin 5 ft. deep.	Sheridan, Wyo.....	7,370	7,174	.....	7,135	[f]3.19
	R. o. m., closed bin 5 ft. deep.	.....do	7,370	7,202	.....	7,094	[f]3.75
	R. o. m., closed bin 15 ft. deep.	.....do	7,370	7,303	.....	6,982	[f]5.26
	Slack, closed bin 15 ft. deep.	.....do	7,355	7,166	.....	6,990	[f]4.96

[a] Heating value of representative mine sample of coal (ash, moisture, and sulphur free), 8,768 calories.
[b] On basis of original heating value of same test portion.
[c] After six months' storage, entire lot in bin.
[d] After six months' storage, upper 6 inches at surface of bin.
[e] Each bin contained 5 to 10 tons.
[f] After two years and three-quarters.

TABLE II. EXPENSE OF STORING AND RECLAIMING COAL

Firm	Tons Stored	Storing	Reclaiming	Total
Hand Storage				
Behner Coal Company, St Louis, stored on ground and reclaimed by hand shoveling.				$.15-.30
St Bernard Mining Company, Nashville Tenn., dumped from wagons, reclaimed directly into wagons.	6000 T.	$.22		
Polar Wave Ice and Fuel Company, St Louis, hand labor.	20000	.48	$.16	.64
Crystal Ice and Fuel Company, Danville, Ill., stored in 65-ton bins by dumping, reclaimed by shoveling.				.17
Ebner Ice and Cold Storage Company, Vincennes, Ind., by hand labor and conveyors, including depreciation and interest.	Conc. pit several 1000 T.	.154	.214	.368
Rock Island Fuel Company, Rock Island, Ill., labor only.	8000 T.	.08	.10	.18
University of Illinois Storage with motor truck and by hand, reclaimed by wagon loader.	5000 T.	.21-.3	.20	.41-.54
Side Hill Storage, estimated in 1907.				.19
Locomotive Crane Storage				
Per cost of locomotive cranes, estimated expense of operating locomotive crane, $1.50 per hour, or 3 cents per ton.				
A large wholesale and retail coal company, (including interest and depreciation in total).		.015	.02	.095
Commonwealth Edison Company, Chicago, labor and materials only.	100000 to 250000 T.	.05	.05	.10
Clinchfield Fuel Company, Dante, Va. Crane and trestle.	130000	.0671	.0655	.1326
A large wholesale and retail company.				.04-.20
Pittsburgh Plate Glass Company, Crystal City, Mo.	40000	.25	.25	.50
Rockford Electric Company, Rockford, Ill.	8000	.10	.10	.20
American Zinc Company, E. St Louis, Ill.	10000	.20	.15	.35
Crerar-Clinch and Company, Chicago, hand and locomotive crane.	15000			.25
Mineral Paint Zinc Company, Depue, Ill.	60000	.05-.04	.04-.06	.10-.12
Estimate by C. G. Hall.				.2628
Missouri, Kansas and Texas Ry., including cost of track.		.035	.035	.07
Chicago, Lake Shore and South Bend Ry.	3000			.12
Grand Trunk Pacific Ry.	40000			
Atlantic Coast Line.	150000	.08	.062	.142 .04-.05
Central of Georgia Railroad	31500	.0258	.0209	.0467
Steam Shovel Storage				
Union Light and Power Company of St Louis, dumped by hand, reloaded by a steam shovel.	30000	.10	.10	.20
Bridge Storage				
Wisconsin Gas and Electric Co., Racine, Wis.	30000	.08	.22	.30
Berwind Fuel Company, Duluth, Minn.				.60
Link-Belt Company, estimate for bridge storage.		.056	.0515	.1075
Calumet and Hecla Mining Company, Calumet, Mich., Hunt System, steam shovel.	500000			
Summer		.15	.07½	.22½
Winter		.15	.11½	.26½
Large swivel bridge.			.06	
Under-water Storage				
Metropolitan Water District, Omaha, Nebr.	4000	.063	.063	.126
Estimate by C. G. Hall.	100000			.1823
Peabody Coal Company, Lemont, Ill. Estimated expense of operation Estimated cost of equipment $13,830.				.162
Illinois Traction System for operation of plant.	2000 16000	.146	.08	.226
Western Electric Company, Chicago.	10000	.05	.04	.09
National Zinc Company, Springfield.	6500	.10	.10	.225 .20

trestles on which side dump cars are used, or in some cases a bridge crane may be used to advantage. One of the great objections to this method of storage is the fact that, if the coal is wet when cold weather sets in, the coal pile will freeze making the reclaiming process difficult.

Methods of Reclaiming

The reclaiming of coal that has been in storage is naturally the reverse of storing it, yet several systems of storing are not adaptable to reclaiming with the same equipment so that other means must be provided. Where the storage pile is adjacent to the boiler room and hand firing is employed, hand shoveling into wheelbarrows or industrial cars is the common practice. This method of transportation gives way to wagons and trucks when the storage pile is not in the yard near the plant and in such cases it is usually found feasible to employ mechanical wagon loaders in place of hand shoveling.

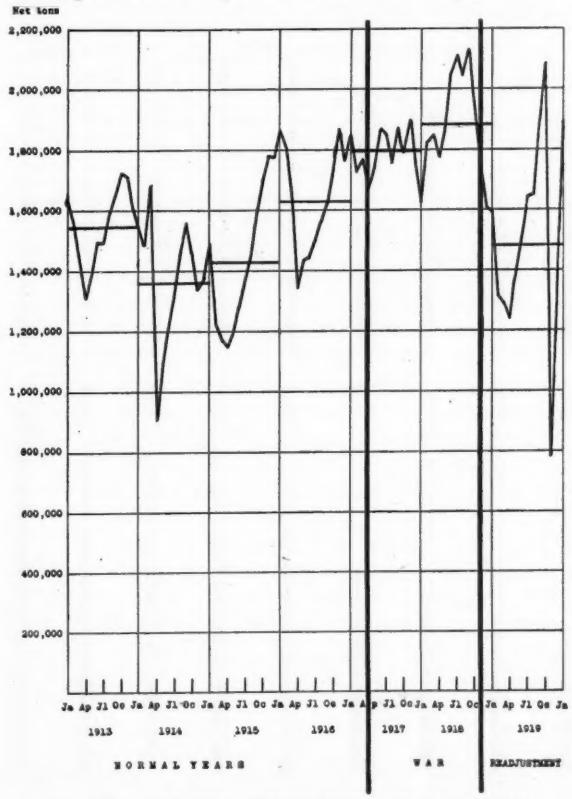


FIG. 12. MONTHLY FLUCTUATION IN DAILY COAL PRODUCTION

Coal stored in piles directly from railroad cars may be reclaimed with wagon loaders, but it is more general practice to use a locomotive crane or steam shovel to load directly to railroad cars or trucks for the reason that in such cases the amount stored is in such quantities that the more expensive equipment will prove an economical investment.

The ideal arrangement for reclaiming, however, is where the storage pile is beside the plant and the conveying equipment of the boiler room can be extended to receive the coal direct from the reclaiming device, and the choice of the latter depends largely upon the conveying system.

Horse-drawn scrapers and dragline and scrapers represent comparatively small first cost, yet are a considerable improvement over hand shoveling and carting. Of more recent and economical equipment available for reclaiming stored coal is the wagon loader delivering to a portable conveying system which carries the coal to the boiler room system. Where an overhead system of coal handling equipment is used for storing the coal, it can, in most cases, with little modification, be used for reclaiming. This applies to the bridge crane and bucket, and

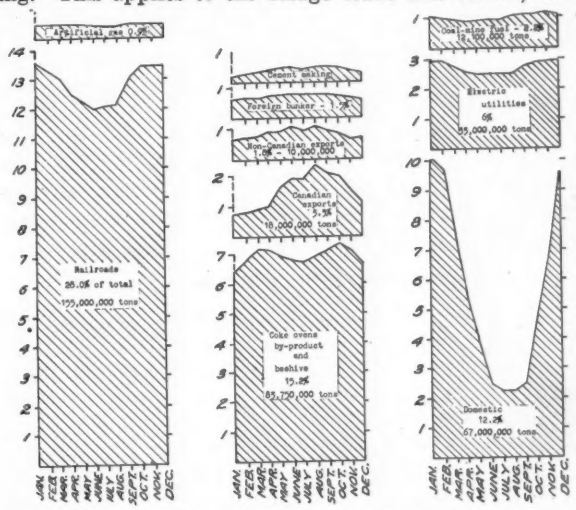


FIG. 13. TYPICAL CURVES OF MONTHLY BITUMINOUS CONSUMPTION

the cable and bucket systems; but where trestle or side hill storage systems are employed, reclaiming equipment must be specially provided.

When to Use Stored Coal

Coal is stored for one principal reason, to insure a continuous supply at the plant. Local conditions must govern in regard to the amount of coal which a plant should store, what it should keep on hand at all times, and when stored coal should be used. Plants farthest away from the mines will find it advisable to store more coal than those near by. Likewise those in climates where freight or boat traffic is likely to be tied up during a portion of the winter will need to store more coal than those situated in a warmer climate.

As the principal cause for slow or poor delivery of coal is due to freight congestion and weather conditions the time to store coal is when these conditions are most favorable and the time to use that in store is when freight is likely to be tied up and weather cold and snowy. A study of local conditions over a period of several years is the only guide which can be relied upon and over and above what is considered desirable for storage a working supply sufficient for two weeks or 30 days should always be on hand for emergency.

As to the expense of storing coal, the variables are so many that no definite figure can be given which would apply in general cases. The cost at a number of individual plants, however, has been obtained by the University of Illinois and is given in Table II. From these figures some idea of the cost per ton for handling the coal by different storage systems may be obtained but local conditions must always be carefully considered.

Coals Used for Steam Generation

CLASSIFICATIONS AND CHARACTERISTICS OF VARIOUS KINDS OF AMERICAN COALS AVAILABLE FOR POWER PLANT USE

WHEN ECONOMY of fuel is the object to be obtained, before even the design of the furnace is considered, the character of the fuel or fuels most certain to be used must be taken into consideration. In the great majority of power plants of this country, the fuel burned is coal in one of its grades ranging from anthracite to lignite, each grade having its individuality and requiring specially designed furnaces, both as regards the chemical constituents of the coal and the sizes available for use. As regards sizes, coals are classified, in a general way, as shown in the following table, the screens used in this classification having round holes:

CLASSIFICATION OF COAL ACCORDING TO SIZE

Sizes	Diameter of holes, inches	
Anthracite	Through	Over
Broken (furnace)	4½	3¼
Egg	3¼	2¼
Stove	2¼	1½
Nut (chestnut)	1½	⅞
Pea	⅞	9/16
Buckwheat No. 1	9/16	5/16
Buckwheat No. 2 (rice)	5/16	3/16
Buckwheat No. 3 (barley)	3/16	1/16
Western Bituminous Coal		
Run of mine	Unscreened Coal	
6-in. lump		6
6 by 3-in. lump	6	3
3 by 1¼-in. lump	3	1¼
3-in. steam nut	3	
1¼-in. nut	1¼	¾
¾-in. nut	¾	⅝
Slack	⅝	
Washed sizes		
No. 1	3	1¾
No. 2	1¾	1⅛
No. 3	1⅛	¾
No. 4	¾	¼
No. 5	¼	0

Eastern Bituminous Coal	Width of slot in bar screen, inches.	
Run of mine	Unscreened coal.	
Lump		1¼
Nut coal	1¼	¾
Slack coal	¾	

The classification of coal according to its relative content of fixed carbon and volatile matter is purely arbitrary and not altogether satisfactory, yet to date it is the most commonly used classification based on the quality of the coal. The great disadvantage with this classification is that it gives no idea of the character of the fuel bed during the burning process. Some coals having practically the same percentages of fixed carbon and volatile matter as others will cake during the coking process, while others do not; again our classification gives no idea what coals will cause clinkers at various furnace temperatures. This classification, however, does give us the volatile matter which is of vital importance in determining the proper furnace proportions, location of arches and baffles. It also affords a reasonable guess as to the heat value of the coal. The classification is, therefore, given with some of the general characteristics as the best guide available for determining the kind of stoker and furnace design and dimensions to use for the coal that will be burned.

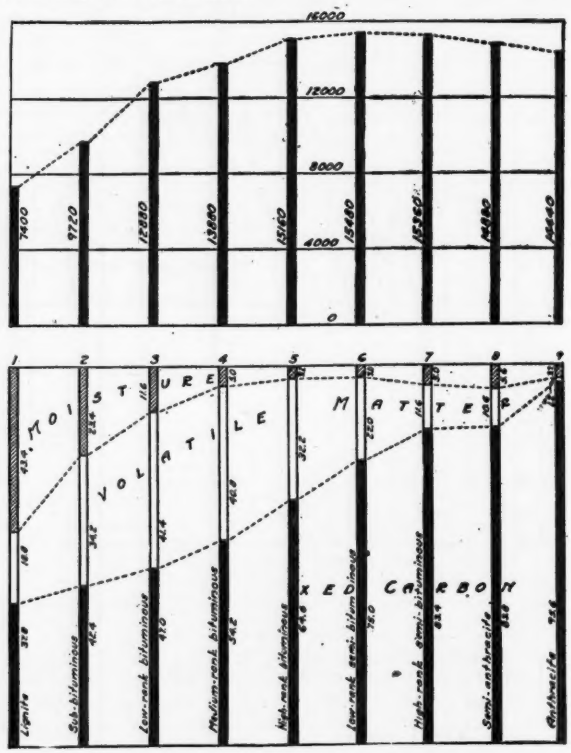


DIAGRAM SHOWING THE CHEMICAL COMPOSITION AND HEAT VALUE OF SEVERAL RANKS OF COAL

The illustration herewith, taken from a bulletin issued by the University of Illinois, shows in a graphic way the classification of different grades of coal and their average heat values.

Anthracite, except in its smaller sizes, is seldom used in power plants owing principally to its price and value for domestic heating. The smaller sizes, which include buckwheat Nos. 1, 2 and 3, are quite commonly used in city plants where smoke ordinances are rigidly enforced and where the price compares favorably with other available grades. And today even the smallest sizes including birdseye and dust are being reclaimed from piles of mine waste and used mixed with bitumin-

ous coal and burned on grates or in powdered coal burning furnaces. Anthracite is composed principally of fixed carbon; the fuel ratio (fixed carbon divided by volatile percentage) is never less than 10.

Anthracite contains so little volatile combustible matter that it may be considered smokeless, as the flame is very short, and with proper handling of the furnace only a small percentage of unburned gases will reach the heating surface even when the distance from grate to boiler shell or tubes is comparatively short. This grade of coal, however, ignites slowly and requires a high temperature for burning. Due to its slow burning qualities the grate surface must be larger in proportion than with bituminous coal, this ratio of grate area varies with the size of coal ranging from 1 to 30 for number 3 to 1 to 40 for number 1 buckwheat. With the smaller sizes forced draft is usually necessary, as the resistance through the grate and fuel bed is too high for natural draft. Loss due to unburned carbon in the ash pit is likely to be greater with small sized anthracite than with bituminous, as it has a tendency to split up under heat, and the small particles drop through the grate.

Most anthracite comes from eastern Pennsylvania, though small fields are found in some of the western states. Its use in power plants is therefore confined almost wholly to the Middle Atlantic States.

Of semi-anthracite coal only a small amount is found in this country, the location of the mines being in Pennsylvania. This coal comes next to anthracite in its percentage of fixed carbon constituent, the fuel ratio being from 6 or 7 to 10. Due to limited amount available, it is relatively unimportant as fuel for steam generation.

Semi-bituminous coal is of great importance to industry today because of its high heat value and comparatively smokeless qualities, but it is not well distributed over the country, being confined principally to the Pocahontas and New River fields of Virginia and West Virginia, the Georges Creek field of Maryland, Windber field of Pennsylvania and the western end of the Arkansas field. Its fuel ratio is 3 to 6 or 7, and it is recognized as the best steam coal in the country. This class of coal is free burning and best results are obtained when the fuel bed is comparatively thick, that is, around 12 in., and frequent firing by the spread system is employed. It ignites readily and burns down to a fine ash without clinkers.

Bituminous coal varies greatly in its characteristics and, because of its wide distribution throughout the country, is of greatest importance to industry. It furnishes most of the coking coal of the country and due to a better knowledge of combustion principles and furnace design, it is growing in favor for power plant use, taking the place of the more expensive semi-bituminous coals. The approximate analysis of different bituminous coals shows a wide variation, the fixed carbon running from 52 to 84 per cent, while the volatile matter constitutes 12 to 48 per cent. The ultimate composition, however, as shown by careful analysis, has a narrower range of composition, as follows: Carbon, 75 to 80 per cent; hydrogen, 5 to 6; nitrogen, 1 to 2; oxygen, 4 to 10; sulphur, 0.4 to 3; and ash, 3 to 10 per cent.

As a rule, bituminous coals ignite readily and the gases distil off rapidly when the coal is subjected to heat; there are, however, exceptions to this rule, such as some Iowa coals which, being comparatively slow to ignite, have a tendency to go out unless the furnace is properly designed. These coals may be caking or non-caking, qualities determined only by burning. Caking coals seem to fuse together and swell when heated and emit a sticky substance over the surface while liberating small streams of gas which burn with a bright yellow or reddish flame terminating in smoke. This spongy, sticky mass may cover the entire grate surface if the method of firing is not well adapted to the coal, and when this condition exists, the draft is greatly interfered with. Such a condition is likely to lead firemen, using hand fired furnaces, to slice the fire which results in clinkers with consequent loss due to unburned coke in the ash pit. The alternate coking method of firing gives best results with this kind of coal. By this method, the mass of coke is broken up when it has passed the sticky stage and only one-fourth of the grate area is affected by the caked coal at any time.

Non-caking or free-burning coals do not fuse or run together when heated. Non-caking coals are common in western states and are also found in Maryland and Virginia. This class of coal ignites readily and burns freely to a fine ash. When used in hand fired furnaces, the fuel bed should be disturbed as little as possible to prevent the burning coal from falling through the grates and the spread method of alternate firing gives best results.

Cannel coal is another variety of bituminous coal found in some parts of Pennsylvania, Indiana and Missouri. It is rich in carbon contents, high in volatile matter which ranges from 40 to 55 per cent, kindles readily and is free burning. Because of its high volatile contents, it is used principally for gas making and is little used in power plants.

Subbituminous is the term adopted by the U. S. Geological Survey for what is commonly known as black lignite, for the reason that such coal has passed beyond the lignite stage in that it is no longer woody, which is one of its distinguishing characteristics from brown lignite. When subbituminous coal is exposed to weather, it slacks rapidly, the lumps becoming brittle and crumbling down to fine particles. This characteristic is used by the Geological Survey for distinguishing it from bituminous coal. The principal fields of subbituminous coal are found in Colorado, New Mexico, Montana, Washington and Oregon.

This class of coal kindles readily, burns freely without caking, runs higher in moisture and ash than the average bituminous coals, the fixed carbon percentage and the volatile combustible constituents run about equal ranging from 30 to 40 per cent. The average heat value of subbituminous coals approaches very closely to that of the lowest grades of bituminous coal and is in the neighborhood of 7000 to 10,000 in samples as delivered from the mines. The two greatest disadvantages in the use of this coal are the high moisture content (from 12 to 25 per cent), and its friability, which causes it to break down so rapidly when exposed to weather.

Lignite, as the term is used by the Geological Survey,

refers to that class of coal that is distinctly brown and generally woody. It is intermediate between subbituminous coal and peat, is so high in moisture, from 29 to 45 per cent, that some special means must be provided in the furnace for driving off the moisture before it will burn, and its heat value is low (5000 to 7000 B.t.u. per pound as received), in comparison with coals. The principal fields of lignite in this country are in eastern Montana, North and South Dakota, Texas and all of the Gulf states. As yet the use of lignite in power plants is very limited, but its use is growing with the development of equipment for burning it in powdered form; this is particularly true of the Texas lignites.

Adapting the Furnace to the Fuel

Combustion Requirements, Grates, Combustion Space and Arches

COMBUSTION of coal in boiler furnaces takes place in two zones, i.e., the fuel bed and the combustion space above the coal. The purposes of the grate are to hold the coals until they are completely burned, to discharge ashes as they are formed and to admit air in sufficient quantities to the lower side of the fuel bed. Above the grate, the furnace must be so designed and constructed as to drive off and burn the volatile matter in the coal, to ignite the coke remaining upon the grate and maintain it at a temperature sufficiently high to cause its complete combustion, to supply air at proper places and in just sufficient quantities to cause complete combustion of the combustible gases that are driven from the fuel bed.

In adapting the furnace to the fuel, the first consideration in hand fired installations is the type of grate bar. When anthracite of fine sizes is the coal available, grate bars made of flat plates with tapering holes ½ in. in diameter drilled in such an arrangement as to give 25 per cent air space will serve well. Larger sizes, say No. 2 buckwheat, are usually burned on grates with rectangular air spaces 1/16 to 3/16 in. wide, giving 30 to 50 per cent air space. With this kind of coal, the fuel bed will pack in burning, which necessitates the use of forced draft, preferably from beneath the grate. The surface of the grate must be smooth to permit the use of tools which are needed in leveling the fuel bed and, due to the thin fire and necessarily low combustion rate, the grate surface in relation to boiler heating surface must be large, the ratio being about 1 to 25, and with the long grates which result, firing will be made easier by inclining the grate surface about 1 ft. from the dead plate to the bridgewall.

Bituminous coals give a wider choice of grates as they are not so likely to fall through the air spaces to the ashpit and they permit the use of shaking grates that will clean the ash from the under side of the fuel bed. The fire is more porous and the draft required is less, so that a thicker fire may be carried and good natural draft will suffice.

Combustion Space

WHILE THE problems involving the grate design have been satisfactorily solved for some time, it has been only during the past 10 yr. that furnace design has reached a point where it could be called satisfactory for different kinds of coal, and there are still many things to be learned before the designer will know for a certainty that the furnace will develop the highest efficiency possible. Coals differ so radically in the amount and character of their volatile constituents that each grade needs special consideration.

Anthracite requires the simplest type of furnace, since the volatile combustible content is low, the combustion takes place principally in the fuel bed and under proper conditions of temperature and air supply the gases are completely burned in a short space above the grate. Ignition is usually slow, so the temperature of the furnace must be higher than is necessary with bituminous coal, hence it is necessary sometimes to build an arch over the fuel bed, thus cutting off from the boiler some of the radiant heat and reflecting it back upon the fuel. This construction is resorted to where the combustion rate is necessarily low part of the time. For this kind of coal the distance of 2 ft. from grate to heating surface is not uncommon and good results can be secured.

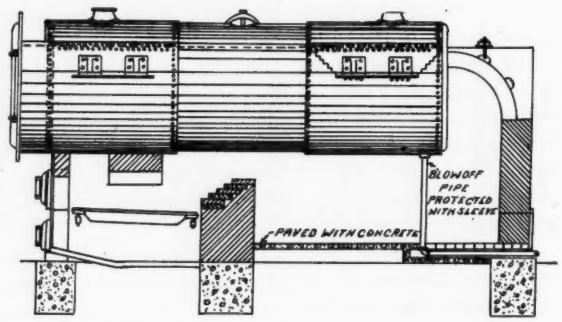


FIG. 1. HAND FIRED ANTHRACITE FURNACE WITH ARCH

As the volatile constituent in the coal increases, however, a greater share of the fuel must be burned in the combustion space above the grate and the furnace must have more volume. In some of our most efficient furnaces, this amounts to as high as 20 cu. ft. per sq. ft. of grate surface where high rates of combustion are the common practice and 6 or 8 to 1 are the general rule. Figure 3 shows what gas composition may be expected from Pocahontas coal with a straight chamber, the rate of combustion varying from 20 to 44 lb. per sq. ft. of grate area.

Influence of Furnace Temperature

TO OBTAIN complete combustion, the temperature of the gases must be maintained sufficiently high in all parts of the furnace and setting where combustible gases are found and the mixture of these gases with air must be sufficiently thorough to cause chemical union, under the influence of heat, of the oxygen in the air and the carbon and hydrogen of the gases.

Extremely high furnace temperatures are not necessarily essential to complete combustion and such temperatures frequently cause clinker, burned grates, melted furnace linings and excessive radiation. The problem, then, of the designer is to construct the furnaces so that

when the boiler is in operation, the temperature will be sufficient to cause the desired chemical combination without an excessive amount of air. This condition is obtained by exposing more or less of the heating surface of the boiler to the radiant heat of the furnace. The theoretical maximum furnace temperature is about 5000 deg. F., but owing to the fusion temperature of the ash,

As the furnaces for the different types of stokers and boilers must necessarily be constructed along different lines the various types will be considered separately.

Hand Fired Furnaces

Hand fired furnaces have gone through many changes in the process of developing standards which

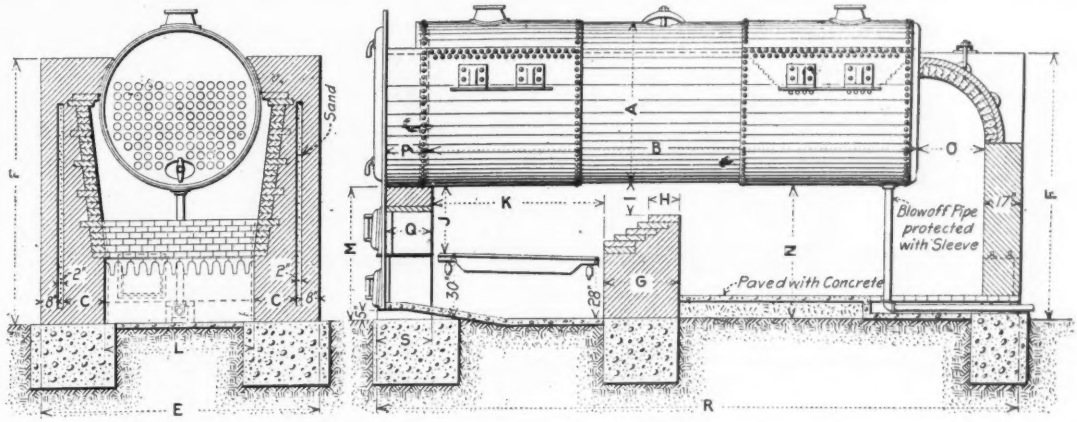


FIG. 2. RETURN TUBULAR BOILER WITH FLUSH FRONT SETTING

grates and furnace linings for power plant boilers, a temperature of 2800 deg. F. is found most satisfactory if the ash will stand this temperature without melting, otherwise it must be reduced to the point where clinker does not form, which is as low as 2000 deg. F. with some

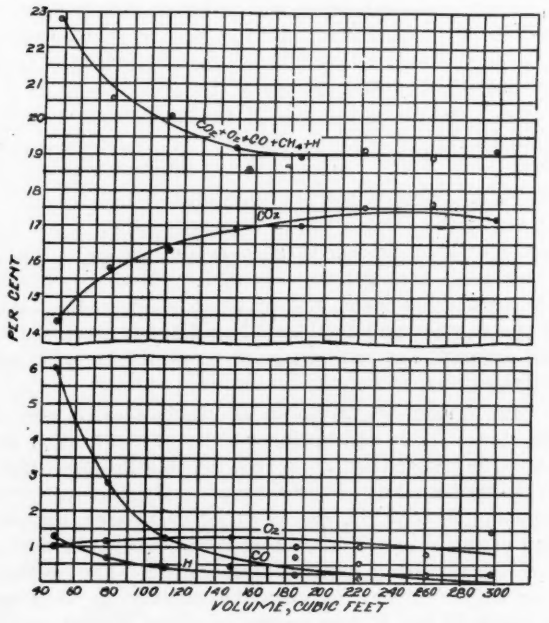


FIG. 3. RATIO BETWEEN FURNACE GAS AND VOLUME OF STRAIGHT COMBUSTIBLE SPACE THROUGH WHICH GAS HAS PASSED

coals of the clinkering class. Of course, the higher the rate of combustion the higher will be the temperature of the furnace, consequently it is essential to know the desired range in the rate of combustion which will occur in the furnace before the baffles and arches are decided upon.

will, when properly handled, give smokeless combustion and high furnace and grate efficiency. No great difficulty is encountered in designing a furnace for anthracite which is a plain grate under the front end of the boiler with a bridgewall at the back of the grate. In case the combustion rate is low at times, a McGinnis arch is extended across the center of the furnace. Where bituminous coal is used, the Smoke Prevention Association has adopted standards which are applicable to coals of the class found in Illinois and are adaptable to any

TABLE I. DIMENSIONS OF BOILER FURNACES FOR SEMI-BITUMINOUS COALS

Horsepower on a Basis of 10 Sq. Feet of Heating Surface per Horsepower	3-inch Tubes	3½-inch Tubes	4-inch Tubes	Diameter of Boiler	Length of Tubes, Feet	Number of Tubes of Each Diameter	Thickness of Inside Furnace Walls, Inches	Over-all Width of Setting, Feet and Inches	Height from Floor Line to Top of Setting Wall, Feet and Inches	Thickness of Bridgewall Inches	Width of top of Bridgewall, Inches	Top of Bridgewall to Shell of Boiler, Inches	Top of Grate at Front to Shell of Boiler, Inches	Length of Furnace, Inches	Width of Furnace, Inches	Floor Line to Bottom of Back Connection, Inches	Floor Line to Bottom of Shell at Rear, Inches	Distance bet. tube sheet and Rear Wall, Inches	Depth of Smoke Box, Inches	Width from Face of Front Wall to Face of Bridgewall, Inches	Overall Length of Setting Walls at Floor Line, Feet and Inches	Thickness of Front Wall at Floor Line, Inches
				A	B		C	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
53	48	44	42	48	12	50-3"	17	8'-0"	8'-0"	21½	9	10	26	48	42	56	55	22	15	17	10'-10"	21
						38-3½"																
61	56	51	48	54	14	30-4"	17	8'-6"	8'-6"	21½	9	10	26	54	42	56	55	22	15	17	10'-10"	21
72	63	61	54	54	14	60-3"	17	8'-6"	8'-6"	21½	9	12	26	54	48	58	57	24	16	18	10'-1"	22
						44-3½"																
83	72	68	64	60	16	30-4"	17	8'-6"	8'-6"	21½	9	12	28	54	48	58	57	24	16	18	10'-1"	22
99	86	86	60	60	16	72-3"	17	9'-0"	9'-0"	26	9	12	28	60	54	58	57	26	16	18	10'-1"	22
						54-3½"																
110	99	96	60	60	18	60-4"	17	9'-0"	9'-0"	26	9	12	28	60	54	58	57	26	16	18	10'-1"	22
130	118	108	66	66	18	66-3"	17	9'-6"	9'-6"	26	14	12	30	72	60	60	59	28	1	19	11'-4"	23
						74-3½"																
147	132	121	66	66	18	60-4"	17	9'-6"	9'-6"	26	14	12	30	72	60	60	59	28	17	19	11'-4"	23
163	149	131	72	72	16	124-3"	21½	10'-6"	9'-10"	30½	14	12	30	72	66	60	59	28	18	20	11'-4"	24
183	167	147	72	72	18	90-3½"	21½	10'-6"	9'-10"	30½	14	12	30	84	66	60	59	28	18	20	11'-4"	24
203	185	164	72	80	18	74-4"	21½	10'-6"	9'-10"	30½	14	12	30	90	66	60	59	28	18	20	11'-4"	24
188	173	161	78	72	16	144-3"	21½	11'-3"	10'-6"	30½	14	12	34	72	72	64	63	28	20	22	11'-11"	26
211	197	181	78	78	16	114-3½"	21½	11'-3"	10'-6"	30½	14	12	34	78	72	64	63	30	20	22	12'-11"	26
234	218	201	78	80	18	82-4"	21½	11'-3"	10'-6"	30½	14	14	34	84	84	64	63	30	20	22	12'-11"	26
260	242	221	84	84	18	180-3"	21½	12'-3"	11'-0"	30½	14	14	34	84	84	64	63	30	20	22	12'-11"	26
						142-3½"																
288	268	245	84	90	18	114-4"	21½	12'-3"	11'-0"	30½	14	14	34	90	84	64	63	30	20	22	12'-11"	26
310	284	267	90	90	18	210-3"	21½	12'-9"	11'-4"	35	14	14	36	90	90	66	65	32	22	24	13'-5"	28
						168-3½"																
334	315	287	90	90	20	114-4"	21½	12'-9"	11'-4"	35	14	14	36	90	90	66	65	32	22	24	13'-5"	28
355	330	302	96	96	18	246-3"	21½	13'-3"	11'-8"	35	14	14	36	96	96	66	65	34	22	24	14'-5"	28
						190-3½"																
392	354	330	96	96	20	168-4"	21½	13'-3"	11'-8"	35	14	14	36	96	96	66	65	34	22	24	14'-5"	28

coal having a lower percentage of volatile. This association recommends that in all cases where the capacity of the boiler is more than 150 hp. a mechanical stoker be installed. Figure 4 shows the double arch bridgewall type of furnace in which the construction consists of two arches which are supported on one side by means of a center pin and the other side rests on the side walls of the boiler setting. These arches extend from the front of the bridgewall to a point back of the bridgewall.

Behind the double arch, a deflection arch is constructed which is built in one or two spans depending upon the width of the combustion chamber. The combined area of the two retorts formed over the bridgewall by the double arch is 25 per cent of the grate area. The gases leaving the furnace are forced through these two openings and the eddying effect caused by the center pier gate of 4 sq. in. per sq. ft. of grate surface. These panels are usually fitted with a ratchet arrangement so as to allow the desired amount of air to enter over the fire. This should ordinarily be about one-half that necessary for the combustion of the coal. Steam jets, to obtain a preliminary mixture of the gases before they enter the retorts, are also standard practice.

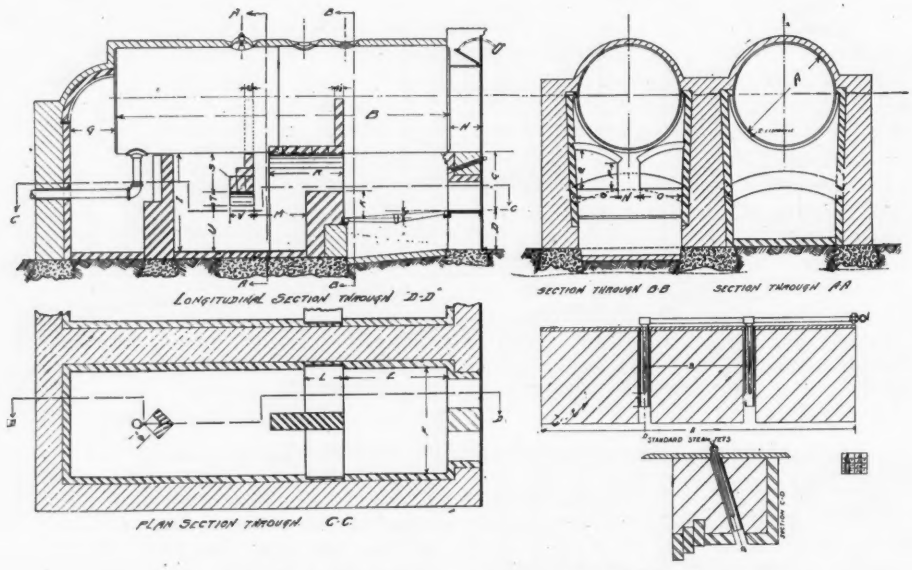


FIG. 4. DOUBLE ARCH BRIDGEWALL FURNACE FOR ILLINOIS COAL

and the back arch which forces the gases down to the bottom of the combustion chamber causes an intimate mixture of the combustible gases and the air while the heated arches retain the heat and keep the temperature high. The boiler shell over the grate is entirely exposed to the radiant heat of the burning fuel bed, but the volatile gases are not allowed to skim along the boiler shell and become chilled. For coal having a lower percentage of volatile combustible, the length of the double arch is reduced, thus exposing more of the boiler shell to the radiant heat of the furnace.

TABLE II. DIMENSIONS OF DOUBLE ARCH BRIDGEWALL FURNACE

A In.	B Ft.	C In.	D In.	E In.	F In.	G In.	H In.	I In.	J In.	K In.	L In.	M In.	N In.	O In.	P In.	Q In.	R In.	S In.	T In.	U In.	V In.	W In.
42	12	18	19	42	42	32	16	42½	½	16½	18	21	9	16½	9	16	27	15	8	19½	19½	8
42	14	18	19	42	42	32	16	44	4	15	18	24	9	16½	11	17	27	17	8	19	19½	8
42	12	20	20	42	42	34	18	42½	½	16	18	20	9	18½	7½	18½	27	15½	8	20	19½	8
42	14	20	20	42	42	34	18	42½	4	16½	18	24	9	18½	9½	17½	27	17½	8	20	19½	8
42	16	20	20	42	42	34	18	42½	4½	15	18	28	9	18½	11½	16½	27	19½	8	20	19½	8
54	14	20	20	42	54	34	18	42½	4	16½	18	24	13½	20½	11½	18	27	19½	9	21	19½	8
54	16	20	22	54	54	34	18	51½	4½	16½	18	24	13½	20½	13½	20	27	21½	9	21	19½	8
60	16	24	22	60	60	36	18	60½	5	17	22½	26	13½	23½	15	22½	30	25	10	23½	19½	8
60	18	24	22	60	60	36	18	60½	5½	16½	22½	30	13½	23½	16	24½	30	24	10	23½	19½	8
66	16	24	24	60	66	38	18	64½	5	18½	22½	26	13½	25½	14½	22½	36	26½	11	25	19½	8
66	18	24	24	66	66	38	18	69	5½	17	22½	30	13½	25½	15½	24½	36	25½	11	25½	19½	8
72	18	26	24	66	72	40	20	69½	5½	18½	22½	30	13½	25½	14½	24½	36	25½	12	25	19½	8
72	18	26	24	72	72	40	20	64½	6	17½	22½	30	13½	25½	13½	25½	36	24½	12	26	19½	8
72	18	26	24	72	72	38	21	65	6	19	20	32	18	20	15½	27½	42	25	12	26	19½	8
72	20	28	24	72	72	38	21	70	6½	17½	24	28	18	20	17½	29½	42	27	12	21	19½	8
84	18	28	26	72	84	38	21	64	6	20	24	26	18	25	14	27½	42	24	12	26	19½	8
84	20	28	26	72	84	38	21	69	6½	19½	24	26	18	25	16	29½	42	26	12	21	19½	8

Note: - Dimensions in the above table apply only for the ordinary conditions and are subject to revision for unusual conditions.

This type of furnace can be used with horizontally baffled water-tube boilers as well as with return-tubular boilers. Provision must be made for introducing air over the fuel bed through the fire doors and the usual practice is to cut a panel opening in the doors having an aggregate of 4 sq. in. per sq. ft. of grate surface. These panels are usually fitted with a ratchet arrangement so as to allow the desired amount of air to enter over the fire. This should ordinarily be about one-half that necessary for the combustion of the coal. Steam jets, to obtain a preliminary mixture of the gases before they enter the retorts, are also standard practice.

Where the combustion rate is lower, this furnace is modified by constructing a drop arch over the grates at a point about one-fourth of the grate length from the bridgewall. The crown of the arch should be on a line 2 in. above the top of the bridgewall and the skewback bricks not less than 12 in. above the grates at the side walls. With this construction the coking method of firing should be employed.

Departing considerably in construction from the double arch bridgewall furnace, is that shown in Fig. 5, which is an arrangement patented by Henry Misostow. The area of the boiler shell exposed to the radiant heat of the furnace and combustion chamber is increased by this arrangement and the brick construction work considerably simplified.

The dimensions given in the table are for coal of the Illinois class and ordinary rates of combustion employed in power plants. Where the volatile constituents in the coal are less or the rates of combustion are lower than say 20 to 30 lb. per sq. ft. of grate area, the location of the V pier is advanced, thus bottling the heat to give the necessary ignition temperature. The openings over the bridgewall between the small wing walls and the face of the V pier aggregate about 20 per cent of the grate surface and between the side walls and the edges of the V pier about 25 per cent. Alternate spread method of firing is recommended for this type of furnace and provision must be made for admitting air over the fuel.

Furnaces for Stokers

The chain grate type of stoker is well adapted to the high volatile coals found in Illinois, Indiana, Iowa

and parts of the West; it will also handle lignites when the furnace is specially designed for driving off the moisture. When caking coals are used, some means of breaking the coke is necessary and excellent results have been secured by providing an inclined coking plate extending from the gate to the grate down which the coal slides by gravity, during which time it is coked by the heat of the furnace, and when the coke strikes the grate, its direction of travel is changed and the cakes of coke are broken up giving air passage through the fuel bed.

With natural draft, these stokers may be forced to care for about 200 per cent of the boiler rating, but with modern methods of applying forced draft in zones, the rate of combustion has in some instances been forced as high as 60 lb per sq. ft. continuous operation. The chain grate stoker has met with success in burning coals high in ash and those having a tendency to clinker. To adapt these stokers for different fuels, the furnaces must have sufficient volume, which varies with the volatile constituents of the coal and the rate of combustion, and the heat must be so reflected upon the green coal as to drive off the moisture in the coal, distil the combustible gases and ignite the coke with sufficient rapidity for the complete combustion of the coke before it goes over the back of the grate.

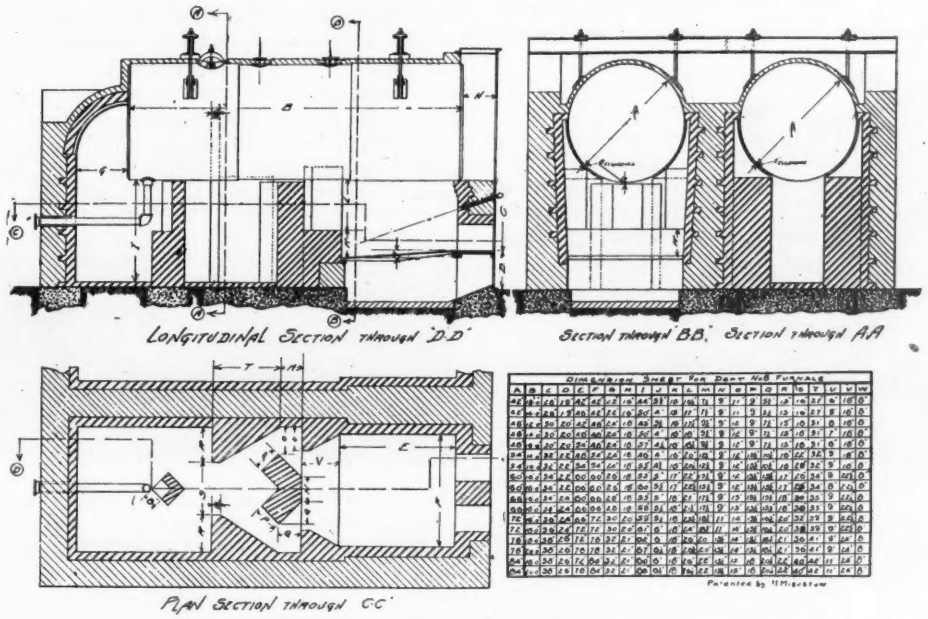


FIG. 5. MISOSTOW WING WALL FURNACE FOR HIGH VOLATILE COALS

As a result of years of research work with chain grates under vertically baffled, horizontal water-tube boilers, the distance of 7 ft. between the grate and first tubes has been adopted as standard in many power plants. This distance is measured from a point on the grate 3 ft. in front of the water back in a line perpendicular to the boiler tubes. The success of a chain grate stoker depends largely upon the temperature maintained in the furnace directly over the green coal; if too low, the gases will not be properly distilled off and burned before reaching the tubes, and smoke will result; if too high, the grates and furnace linings will melt down. This condition is remedied by either increasing the rate

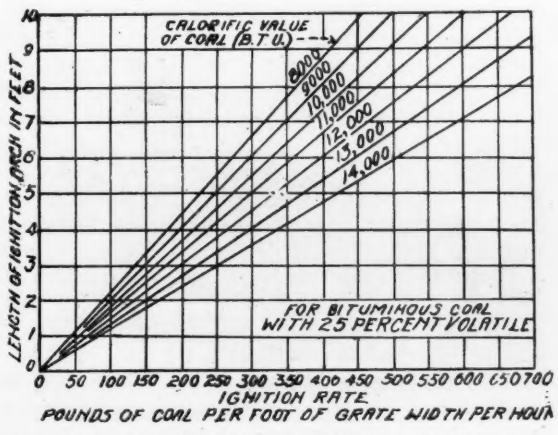

CALORIFIC VALUE OF COAL (B.T.U.)
9000
10,000
11,000
12,000
13,000
14,000
FOR BITUMINOUS COAL WITH 25 PERCENT VOLATILE
LENGTH OF IGNITION ARCH IN FEET
0 1 2 3 4 5 6 7 8 9 10
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700
IGNITION RATE
POUNDS OF COAL PER FOOT OF GRATE WIDTH PER HOUR

FIG. 6. RELATION OF ARCH LENGTH TO IGNITION RATE

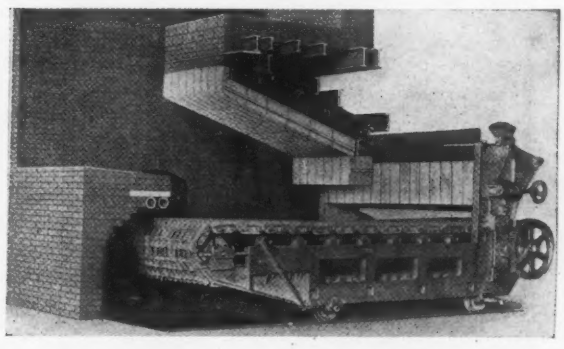


FIG. 7. CHAIN GRATE STOKER

of combustion, or arranging the arches so as to bottle up the heat to get higher temperatures, and reversing the order to get lower temperatures. Figure 6 shows the length of ignition arch recommended by T. A. Marsh for bituminous coal of different heat values and at various rates of combustion. These arches are commonly set 15 in. high at the front and pitched 3 in. to the foot.

Front feed gravity stokers are well adapted to a wide range of coals. They burn satisfactorily coals of high or low volatile combustible content, but are unsuitable for lignite fuels or fuels high in ash, particularly ash with a tendency to clinker. Caking coals also give trouble. The same general principles of temperature control with a progressing fuel bed are found here as with a chain grate, the great difference being that the coal slides or tumbles down a grate surface that is most certain to be rougher in some spots than others which causes a fuel bed that is not uniform and the ash is not dumped continuously.

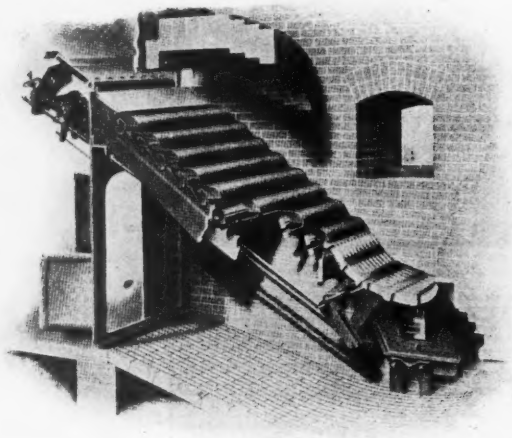


FIG. 8. FRONT FEED GRAVITY STOKER

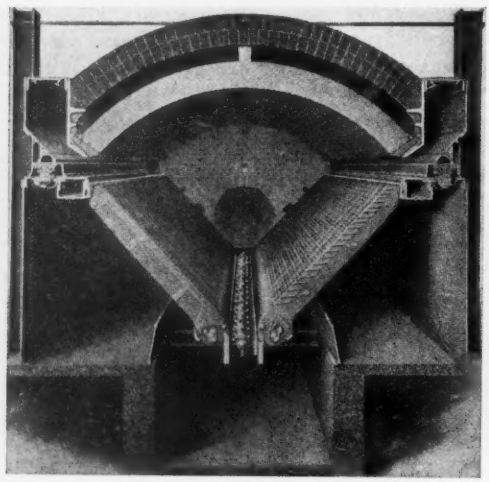


FIG. 9. DOUBLE SIDE FEED STOKER

Double side feed stokers have substantially the same characteristics as the front feed, due, however, to the arch which is built over the grates the furnace temperature is usually higher and the designer is left with little opportunity to reduce this temperature by reducing the bottling effect of the arch. The latest designs of side feed stokers are equipped with what are called clinker grinders that remove the ash and clinker automatically as it accumulates.

Underfeed stokers of the horizontal retort type are admirably adapted for burning high volatile coals which have an ash with a high temperature fusing point. While not confined to use with small boilers, their greatest field has been in replacing hand fired furnaces where difficulty with smoke had been experienced. Due to the necessary thickness of the fire carried, air must be forced through the fuel by some mechanical means. This makes it a desirable stoker in plants where the load fluctuates widely as the rate of combustion can be increased rapidly. No ignition arches or baffles are required.

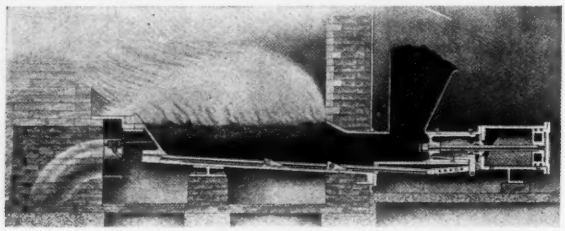


FIG. 10. HORIZONTAL UNDERFEED STOKER

The inclined or gravity underfeed stoker combines the features of the front feed and underfeed stokers resulting in a furnace for high volatile coal having an ash with a high temperature fusing point either caking or non-caking. It is common equipment for boilers of large size which are subjected to overload peaks and sudden demands ranging as high as 400 per cent of normal rating. Forced draft is necessary.

Sprinkling type stokers merely take the place of the fireman who shovels the coal into the furnace. In these, fine coal must be used and a furnace design which works well with hand firing should give better results when equipped with a sprinkling type stoker, as the feed is practically continuous, but in small quantities, and the frequent opening of the firing door is eliminated.

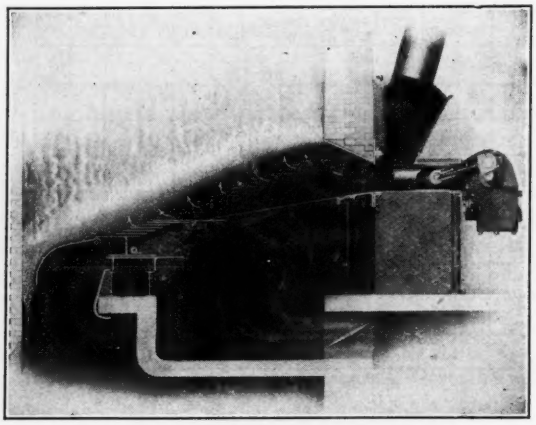


FIG. 11. INCLINED UNDERFEED STOKER

Adapting Firing to the Fuel

Various Standard Firing Methods

WHILE the principles of the combustion of all coals are the same, it has already been shown that the different coals act differently under the influence of heat and for this reason what may be the best way to handle one kind of coal may prove decidedly unsatisfactory with another coal. The general types of coal will therefore be considered separately and suggestions will be made as to how various difficulties may be overcome when they are encountered so that they may be prevented from occurring again.

Steam sizes of anthracite are small and for best results must be fired thin, at frequent intervals when the color of the fire has just turned from the white heat to light red. An experienced fireman can at a glance determine where the thin spots are in the fuel bed and these should be given more coal than the rest of the surface. For furnaces having two doors, the alternate spread method of firing should be employed; this method consists in spreading a thin layer of green coal evenly over one side of the grate and waiting until it has become thoroughly ignited before firing the other side of the grate. Skill in spreading the coal thinly and evenly over the fuel bed will avoid to a great extent the use of the leveling bar, which should be used only for the purpose of keeping the fuel bed level and the thin spots covered.

Cleaning must of course be done when the bed gets so thick that it is interfering with the draft to the extent that the possible load condition cannot be easily met and as a rule a fuel bed of No. 1 buckwheat should not grow thicker than 8 in. and No. 2 buckwheat not over 10 in., preferably not over 6 and 8 in. respectively. In case an automatic damper regulator operates the forced draft fan, it is important that the fuel be supplied to the fire in proportion to the speed of the fan which delivers the air to the furnace.

Successful hand firing of bituminous coal is accomplished by one of three general methods; these are known as the coking method, spot firing and alternate-spreading method.

Coking Method

When caking coals are used, best results are obtained by the coking method if properly done; it requires more work on the part of the fireman than other methods and is likely to be carelessly done. By this method, comparatively large charges of coal, which should be broken to sizes not larger than the fist, are heaped in a pile extending across the front of the furnace, just inside the dead plate, the amount of coal per charge being sufficient under ordinary conditions to hold the steam up for about 15 min. This heap of green coal is allowed to remain in this position until time for the next firing; during this time, the heat of the furnace is driving off the volatile matter in the coal and the remaining coke is ignited and brought up to the furnace temperature. With caking coals, to which the method is best suited, the charge becomes a solid mass through which air passes with difficulty.

At the next firing, this mass of burning coke is broken up and pushed to the back section of the grate with a hoe, spreading it as evenly as possible over this surface, making certain that all holes are covered. Then green coal is piled at the front of the grate as previously described. The volatile matter coming from the fresh fuel passes over the incandescent coke and is burned without smoke, provided sufficient air is admitted over the fire and thoroughly mixed with the gases. This method requires the fireman to handle the fuel twice and he will have a tendency to resort to the spreading method, which does not give best results with caking coals.

Spot Firing

Spot firing is a modification of the coking method; it requires more skill and the results are not quite so satisfactory as can be secured by a careful fireman using the coking method, but is decidedly better than the spread method for high volatile caking coals. When the fire door is opened the fireman can determine by a quick glance the low spots where the fuel has burned out, and on each of these spots a shovelful or two of coal is put. By this method, firing must be done frequently, otherwise holes will develop with resultant loss due to excess air. Some raking will be necessary to break up the lumps of coke, but the fuel bed as a whole will not be disturbed. The volatile matter is driven rapidly from the green coal which has been fed in this way and being surrounded by gases rising from the incandescent coke, is quickly burned when the air supply is properly distributed.

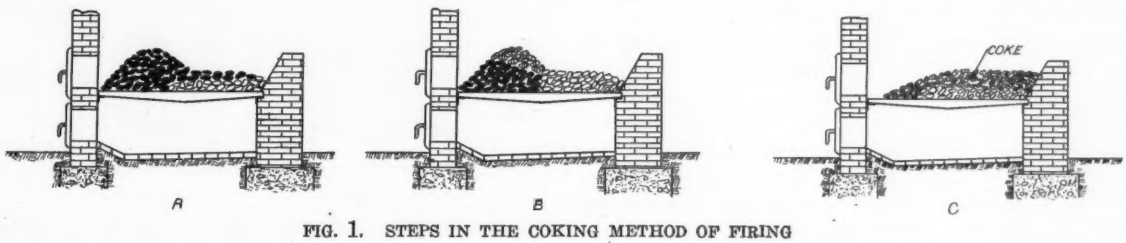


FIG. 1. STEPS IN THE COKING METHOD OF FIRING

Alternate Spreading Method

Non-caking high volatile coals are fired most economically by the alternate-spreading method. By this method, small charges are fired at intervals of about 5 min. on either side, thus making the interval between consecutive firings on one side 10 min. A thin layer is spread evenly over one-half of the grate surface at a time and while it is being coked, the other half of the fuel bed is at its highest temperature; thus the furnace temperature is kept high and the volatile gases are brought quickly to the ignition temperature. Carry as thick a fuel bed as the draft available will allow, for a thin fire with strong draft soon burns into holes. With large

grate area, it may prove more satisfactory to divide the grate into four sections instead of two as illustrated.

The amount of coal charged at each firing depends upon the method of firing and the load carried, but should be as uniform as possible under the existing conditions.

Cleaning Fires

A bright ashpit is an indication of a clean fire. If dark in spots, clinkers are usually the cause and they should be broken up and taken out. This is done by running a slice bar between the clinker and the grate, lifting the clinker just sufficiently to break it, but not to mix the ash with the burning coal which will only aggravate the clinker trouble. When the ashpit becomes dark and ordinary shaking of the grate does not relieve the condition, the fuel bed should be cleaned. To do this with stationary grates, one side of the fire should be allowed to burn low, then the live coals are winged to the other side of the grate and the accumulated ash is pulled out of the fire door with a hoe. When the grate is clean, a thin layer of live coals is winged back on the bare space and covered with a thin layer of green coal. When the clean side of the grate has come back to good working condition, the other side may be cleaned in a like manner.

When dumping grates are installed, the cleaning is usually done in sections, one-fourth of the surface at a time. The fire on the section to be cleaned is allowed to go nearly out and is then dumped directly to the ashpit without the necessity of winging the live coals off as they drop to the ashpit, and can readily be quenched with water. Large clinkers must be pulled out at the fire door. Live coals are then hoed or raked from another section of the grate and the fire started as with stationary grates. The process is repeated with each section of the grate.

Handling Stokers

As regards the handling of different stokers with the different kinds of fuel, there is little to be said, as once the stoker is installed the method of operation is fixed regardless of the kind of coal being used. As previously stated, however, various stokers are better adapted to some kinds of fuel than others and it is when they are being used out of their special field that they give trouble.

All chain grate stokers have two adjustments which can be made to suit variation in load conditions and difference in the burning qualities of the coal used, these are the rate of travel of the grate and the thickness of the fuel bed. It is essential that the coal be burned completely before it goes over the end of the grate to the ashpit, but the fire should be dead only a short distance in front of the water back as the excess air admitted here will cause undue losses. The adjustments should be made, then, so as to secure complete combustion just in front of the waterback. Coal which ignites slowly will burn slowly and to be completely burned before it reaches the waterback, must travel slowly. It will require, then, a thicker fuel bed for the same load than will a coal that burns rapidly. It frequently happens that, upon trial, the coal does not ignite properly, or it may ignite but go out farther back on the grate without burning completely; or, to accommodate the load, the fuel bed may have to be so thin that it burns out too early and causes an excess of air in the furnace. These conditions require a change in the design of the ignition arch or bridge wall to reflect the heat upon the fuel so as to maintain the proper temperature throughout the length of the grate. This subject has been previously treated.

Front and double side-feed gravity stokers are operated the same regardless of the kind of coal used. The greatest difficulty met with these stokers is in keeping the grates covered, for holes will develop, due to the caking of the coals and the fusing of the ash. This necessitates the use of a bar to break up the cakes and allow the free flow of the coal. On either of these types of stokers there is but one adjustment of the fuel which is the rate at which it is fed to the grate.

Likewise with underfeed stokers, there is no difference in the method of handling different kinds of coal. The attendance consists in keeping the coal supplied in proper proportion to the load and regulating the draft to supply the necessary air for complete combustion. The work of keeping the fuel bed free of clinkers and of dumping the ashes will vary with the fusing temperature of the ashes, the load carried and the percentage of ash in the coal.

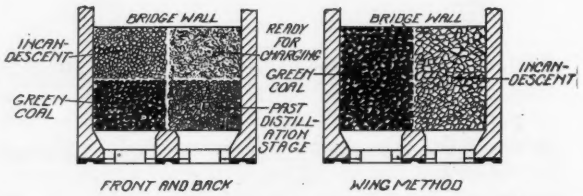


FIG. 2. CONDITIONS OF FUEL BED IN ALTERNATE METHODS OF FIRING

Sprinkling type stokers fire the various kinds of coal in precisely the same manner, which is the spread system, small quantities being delivered at very frequent intervals. Both the frequency and quantity are adjustable to suit the load and fuel bed conditions. It may be necessary to level the fuel bed occasionally with some sprinkling type stokers, as the coal may not be evenly distributed, but, as a rule, the fuel-bed should be disturbed as little as possible for the natural operation of the stoker forms a porous bed which is ideal for admission of air through the grate.

Adapting Firing to the Load

The amount of coal required over any given period of time depends principally upon the load being carried and with hand-fired furnaces there are two methods of supplying the varying amount. One is by varying the intervals of firing, the other by varying the amount at each firing. The quantities that may be fired are limited by the size of the grate and the intensity of the draft. A fair average for a total available draft of 1 in. in the uptake is 2 to 2½ lb. per sq. ft. at intervals of 5 min. With a stronger draft, the intervals may be shortened to 3 min. and with a sluggish fire, they may be lengthened to 8 min. but should not under ordinary circumstances be longer than 10 min. If the load conditions

require less coal, the amount at each firing should be reduced.

Small and frequent firings make the coal supply more nearly proportional to the air supply which in most hand-fired furnaces is constant; they also reduce the caking of the fuel and the chances of holes developing in the fuel bed.

Proper combustion depends greatly upon the fuel bed which is governed by the available draft and the character of the coal. In the ordinary power plant using run-of-mine coal broken to the size of the fist where the available draft in the breeching is about 1 in. of water, the best thickness of the fuel bed is from 4 to 8 in. With coking coals, the fuel bed must be thinner than with coals that are free burning, and small sizes must be fired thinner than those of larger size where the available draft is the same. A fuel bed that is too thick will be stagnant, dark in color, somewhat smoky and is subject to clinker formation. The indication that a fuel bed is too thin is the rapid development of holes in the fire. Firing period of 5 min. intervals have proved to be the most economical and sufficient coal should be spread over the fire to prevent holes of any size from developing between firing periods.

Load conditions on stoker fired boilers are readily taken care of by increasing or decreasing the speed of the stoker and the amount of coal fed to the furnace and regulation of the draft to give air in proportion to the amount of coal.

Preventing Ashpit Loss

Ashpit loss in average well operated hand-fired power plants amounts to about 3 per cent of the heat value of the coal, but may easily run much higher if

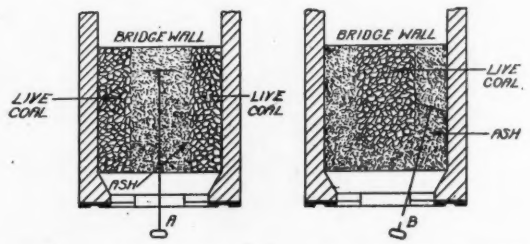


FIG. 3. CLEANING STATIONARY HAND-FIRED GRATES

all precautions are not taken to prevent waste here. Fine coal necessarily requires a grate with smaller air space than large sizes, but small air space requires greater draft and more frequent shaking and cleaning which are likely to result in greater loss than larger air spaces in the grate. Green coal should not be thrown upon a bare grate but upon a thin layer of burning coal which will prevent its falling through the grate.

The loss due to coal sifting through the grates of chain grate and gravity stokers may amount to considerable, particularly with small sizes of non-caking coals, and in such cases it is common practice to provide a hopper or some other means of catching this coal and coke and returning it to the furnace. Tempering the coal with water before it is fed to the stoker hopper is resorted to in many plants to aid coking and prevent sifting through the grate. It is important to adjust the stoker so that the coal is entirely burned before it is discharged to the ashpit, as the loss from poor adjustment may be considerable.

Draft

Air Supply to the Furnace and Methods of Draft Control

SO FAR in the discussion of firing coal, little has been said about the air necessary for the combustion of the coal; the fact is, however, that no combustion can take place without air and the method of introducing it into the furnace is of great importance. Under ordinary good conditions, 1 lb. of coal will require 15 lb. of air for complete combustion, which means that for each pound of coal burned 200 cu. ft. of air must be supplied; at a combustion rate of 25 lb. per sq. ft. of grate area per hour, the volume of air required would be 5000 cu. ft. per sq. ft. of grate area per hour. If the air space through the grate were 50 per cent of the area and all the

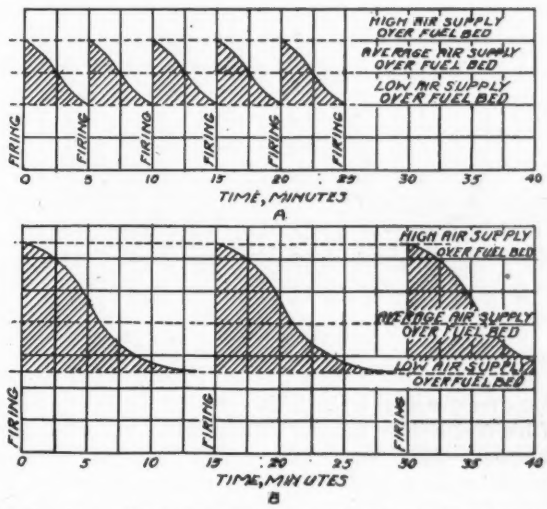

HIGH AIR SUPPLY OVER FUEL BED
AVERAGE AIR SUPPLY OVER FUEL BED
LOW AIR SUPPLY OVER FUEL BED
FIRING
0 5 10 15 20 25 30 35 40
TIME, MINUTES
A
HIGH AIR SUPPLY OVER FUEL BED
AVERAGE AIR SUPPLY OVER FUEL BED
LOW AIR SUPPLY OVER FUEL BED
FIRING
0 5 10 15 20 25 30 35 40
TIME, MINUTES
B

FIG. 1. INFLUENCE OF FREQUENT FIRING ON LOSSES DUE TO AIR SUPPLY; CLEAR SPACE BETWEEN CURVE AND DOTTED LINE REPRESENTS LOSS DUE TO EXCESS AIR, CROSS-HATCHED SPACE THAT CAUSED BY INSUFFICIENT AIR

air necessary for combustion came through the grate, the velocity through the openings would be 2.8 ft. per sec. Good combustion, however, requires that approximately half the air needed must be admitted over the fuel bed, so the velocity through the air spaces in the grate will be 1.4 ft. per sec.

The force for drawing this air into the furnace is termed draft and is usually measured by a U-tube vacuum gage filled with water or some modification of this instrument. The propelling force may be created naturally by means of a chimney or artificially by means of fans either drawing the air and gases from the boiler, called induced draft, or forcing air into the furnace, called forced draft.

Since variations in the load carried by the boiler require like variation in the amount of coal burned, the amount of air must also be delivered in proportion to the load. To cause this variation in delivery, other conditions remaining the same, the impelling force or draft

must vary in proportion to the load. Thus the entire mechanism for supplying coal to the furnace and regulating the air supply should work in proportion to the load carried by the boiler.

Instruments for Observing Combustion Conditions

Without the aid of automatic control devices, the fireman encounters so many variables that it is next to impossible for him to maintain economical conditions and he should be provided with the instruments which will indicate as far as possible just what his conditions are. The steam pressure gage is necessary not only from the standpoint of safety, but for uniform operation the pressure should be kept within close limits and the gage is essential for this purpose.

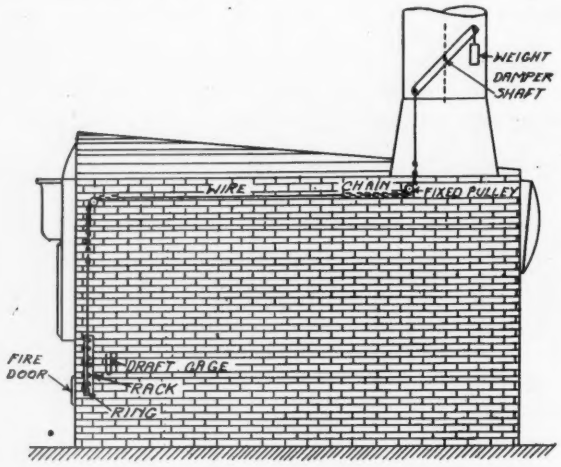


FIG. 2. CONVENIENT DAMPER CONNECTION

Next in importance is the draft gage with a connection over the fuel bed. This gives the fireman an idea of his fuel bed condition. With a uniform load and the damper position unchanged, a rapidly falling draft as shown by the gage indicates the development of a hole in the fire which is likely to be followed by a slight falling off in steam pressure. The gradual accumulation of ashes from the time the fire is cleaned will be indicated by an increase in draft necessary to carry the load.

In addition to the draft gage over the grate, another to indicate the draft just in front of the damper is a big aid to the fireman, for by means of this an accumulation of soot on the tubes will show up by a gradual increase in the differential between the furnace and breeching. A fallen baffle or one which has a hole in it will cause a decrease in differential draft below normal conditions and an increase in load on the boiler will demand more gases through the tubes with a consequent increase in differential draft.

To determine whether or not the furnace is burning the fuel efficiently, some means for analyzing the flue gases is essential and the proper regulation of the draft will be indicated when the gas analysis shows that combustion has been complete and the excess of air is low. The value of flue gas analysis will be discussed in detail later.

A flue gas pyrometer or thermometer which indicates the temperature of the escaping gases is also a great aid to the fireman in regulating his draft, as excess air, which is one of the principal causes of chimney losses, will be shown by a reduction in flue gas temperature below what it should be with the most efficient combustion; this is accompanied by an increase in differential draft. Soot or scale accumulation will be indicated by an increase in flue gas temperature as will also a fallen or badly leaking baffle. When flue gas temperature readings are compared carefully with draft losses through the setting, CO_2 readings, and load conditions indicated or recorded by a steam flow meter, an absolute check on the efficiency of combustion and heat absorption and condition of the boiler setting is available to the intelligent engineer.

Hand control of draft requires careful attention and an understanding of the readings of all these instruments and when relied upon, convenient damper connections should be provided so that the fireman can vary the damper position from the front of the boiler where he may have full view of the instruments used in the regulation of the draft. Lack of a convenient means for adjusting the damper position is likely to result in the bad practice of regulating draft by means of the ashpit door. While the amount of coal burned can be controlled by allowing more or less air to enter through the ashpit door, restricting the entrance of air under the grate causes more air to be drawn through the leaks in the setting and through the fire door and the heating of the grates and ashes in the fuel bed which is likely to result in clinkers. For best combustion, the ashpit door

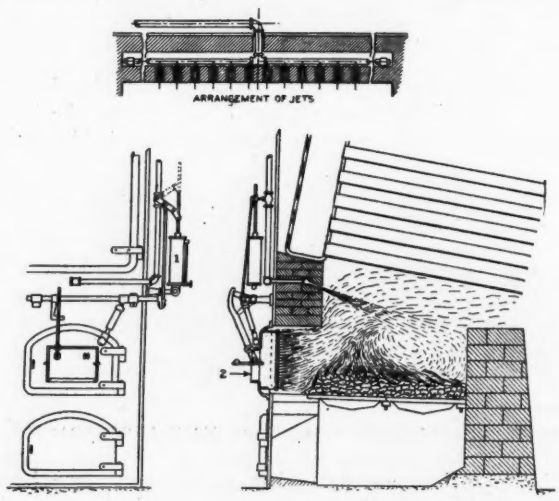


FIG. 3. AUTOMATIC REGULATOR FOR VARYING OPENING IN FIRE DOOR AND ADMITTING STEAM OVER FIRE

should be kept open. With hand-fired furnaces, the amount of air admitted over the fuel bed should be varied, being greatest immediately after firing and gradually decreasing until all the volatile matter has been driven off the coal when it should remain constant at about the same quantity as that which enters through the fuel bed. It is not practicable for the fireman to attempt this by hand, but there are automatic devices which are so designed as to open a vent in the firing door when it is thrown open for firing purposes and when the door is again closed, the vent gradually closes, thus admitting the necessary varying quantity of air during the coking process. A steam jet in the form of an ejector

is sometimes used to good advantage for introducing air and mixing the gases during the coking process.

Automatic Draft Control

Much better results can be obtained with automatic regulation of the draft than when it must be done by the fireman. In most cases, automatic regulation is based on the steam pressure, a variation of which causes the draft controlling mechanism to shift, either admitting more air, when the pressure drops, or cutting off the supply when pressure increases. Some schemes, however, depend upon changes in the rate of steam delivered for controlling the air supply. These changes are so rapid, in many cases, that some scheme for reducing the sensitiveness of the mechanism must be employed.

Hand-fired and many natural draft stoker installations have a simple damper regulator mechanism for this purpose, but when forced draft is employed the control system becomes more complicated, which involves regulation of fan engine and stoker speed as well as the damper position to maintain a definite draft over the fuel bed.

In plants where natural draft is depended upon, the common practice is to install an automatically operated damper in the common breeching with an auxiliary hand operated damper for each boiler, which gives a means of distributing the load among the various boilers in the plant. Another arrangement, however, is to connect all individual dampers to a line shaft that is operated by the damper regulator with adjustable dis-

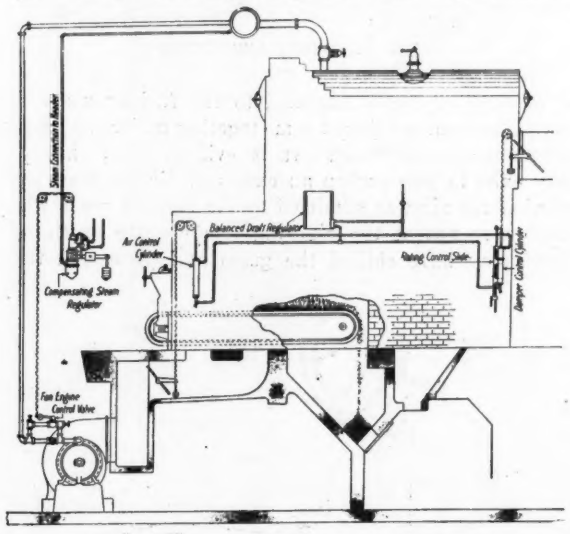


FIG. 4. DIAGRAM OF BALANCED DRAFT CONTROL SYSTEM AS APPLIED TO FURNACE WITH CHAIN GRATE STOKER

engaging chains between the line shaft and the dampers, and thus do away with the stack damper. Dampers which are operated automatically should be so adjusted that the device cannot close the damper completely.

When induced draft is employed no damper is needed in the stack as the speed of the fan is controlled by the damper regulator.

With increased rates of combustion now common in stoker installations and the use of small sizes of coal, the resistance of the fuel bed to the passage of air becomes so great that the use of forced draft is necessary to eliminate losses due to leaky settings. At the same time, it is essential to supply enough induced draft to carry away the gases of combustion for otherwise there would be a pressure in the furnace which would result in danger to the fireman and gas in the boiler room due to leaks in the setting.

To overcome this difficulty, several systems of automatic control have been developed; the first of these is based entirely upon variations in steam pressure, while others control part of the draft machinery in unison with the steam pressure and the rest by variations in the pressure over the fuel bed.

Very good results have been obtained where a damper regulator is connected not only to the damper, but also to the throttle valves of the fan and stoker engines in such a way that a drop in steam pressure would cause the damper to open wider, thus increasing the differential draft, and increase the speed of the fan and the

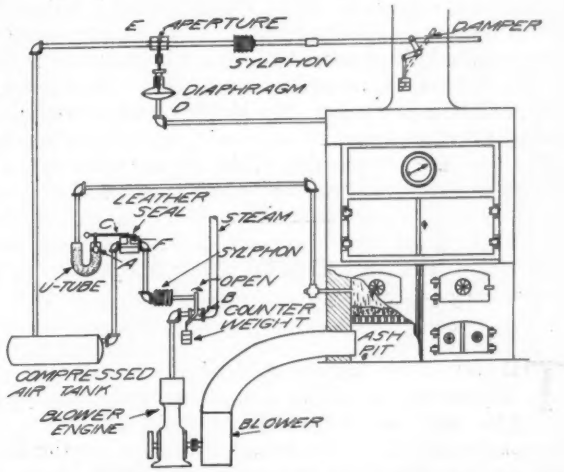


FIG. 5. DIAGRAM OF SYSTEM CONTROLLING DAMPER POSITION BY STEAM PRESSURE AND UNDER-GRATE PRESSURE BY VACUUM IN FURNACE

stoker feeding mechanism, thus providing greater forced draft and more fuel to be burned in a given time. The result of this combined change is an increase in combustion rate and consequent higher rate of evaporation to meet the demand for more steam. The change in damper regulator position should take place gradually until the desired pressure has been restored. A lessening in demand for steam will naturally result in an increase in pressure when the control system works in the opposite direction until the pressure is reduced to the desired point. The difficulty which is encountered with such a system is that, with a variation in the character of the fuel bed, load carried by the boiler and soot accumulation on the tubes, the vacuum or pressure over the fuel bed is not constant and a loss in efficiency of combustion is attributed to this cause.

Recognizing that the critical draft is that existing over the fire, has led to the development of two systems; one has a steam regulator which controls the speed of the fan and stoker feeding mechanism in proportion to the load carried as reflected in the variation of steam pressure. This affords the necessary air pressure and fuel, but does not control the position of the damper in the breeching which in turn controls the air pressure over

the fuel bed; so entirely independent of the steam pressure, a swinging diaphragm is provided with connection to the furnace on one side and to atmosphere on the other. This diaphragm is so adjusted that when the desired draft is maintained in the furnace it will remain in an upright position, but a slight change in draft will cause it to operate a pilot valve admitting water pressure to an operating cylinder which causes a movement of the damper in the direction to restore the desired furnace pressure. With some types of stokers, the swinging diaphragm also controls the position of a damper in the air supply line.

Still another system depends upon variations in steam pressure to control the position of the damper in the breeching, but depends upon the overfire vacuum to regulate the speed of the blower and consequently the ashpit pressure. For example, if the steam demand suddenly increases, the damper opens and causes a greater suction to the furnace. Since the apparatus is adjusted for a constant overfire vacuum, this damper change causes the ashpit pressure to increase immediately sufficiently to bring the overfire vacuum back to the constant and predetermined point. The higher ashpit pressure increases the rate of combustion to conform to the increased boiler load, and the opening of the damper takes care of the greater volume of gases given off by the fuel bed.

Measurement of CO_2

IMPORTANCE OF GAS ANALYSIS AND INSTRUMENTS USED IN POWER PLANTS

THERE is but one way to determine whether or not the combustion of the furnace gases has been complete and that is by analysis of the flue gases. If no combustible gases are found in the flue, combustion has been complete, but in securing this result too large a proportion of air may have been used so that the heat lost up the chimney is more than it need be. This will also be shown by an analysis of the flue gases. Under average good conditions, the heat loss in dry flue gases amounts to 26 per cent of the heat in the fuel, but this can easily be increased by supplying more air to the furnace than is needed, which condition can be positively determined only by a gas analysis.

An analysis of the gases is, therefore, desirable in all plants, the manner of taking the analysis, however, will depend largely upon the size of the plant.

For regular boiler operation, a complete analysis of the flue gases is not essential; in fact, if the percentage of carbon dioxide, CO_2, is known, simple calculations, tables or charts will afford the plant operator the information he needs to hold his combustion efficiency at the highest point.

Carbon dioxide, CO_2, is the result of complete combustion of carbon, which is the principal combustible element in fuel, and with perfect combustion which assumes complete combustion without an excess of air the percentage of CO_2 in the gases would be 21 by volume. Thus it will be noted that all the oxygen of the air has united with the carbon of the fuel to form CO_2, leaving in the gases CO_2 and nitrogen N_2.

This condition, however, never exists in the practical power plant due to slight imperfections in all furnaces. If complete combustion is secured, an excess of air will invariably be found necessary. Incomplete combustion is indicated by the presence in the gases of carbon monoxide, CO, which is formed when an insufficient amount

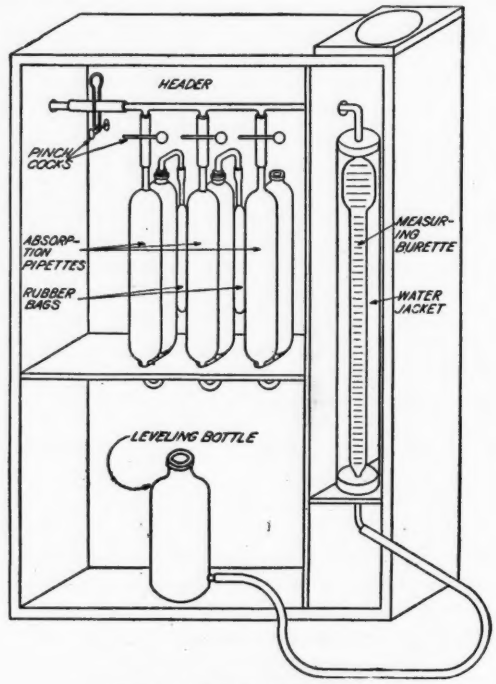


FIG. 1. ORSAT APPARATUS

of oxygen, or air, is supplied to the fuel or when the oxygen and carbon do not come together under the proper temperature conditions. It is evident then that CO may exist in gases when an excess of air has been supplied if the air was admitted to the furnace gases when they were not at the kindling temperature or the air itself may have chilled the gases and prevented their

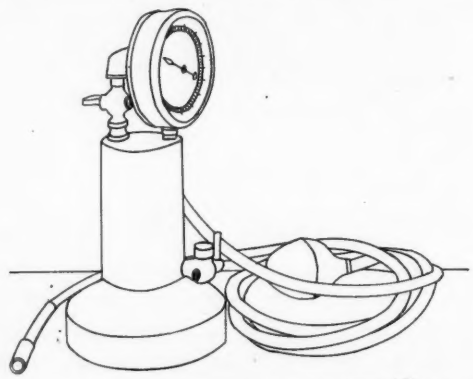


FIG. 2. CO_2 ANALYZER WHICH READS CO_2 DIRECT ON VACUUM GAGE

complete oxidation. Such a condition is indicated by the presence in the flue gases of CO_2, CO and O_2.

These three gases are the principal constituents of the flue gases which determine the completeness and efficiency of combustion and are therefore of greatest importance to the engineer. There are, of course, other

gases which are formed in the furnace but these make up only a small percentage and are therefore relatively unimportant.

Gas Analysis Instruments

In the power plant, the apparatus most commonly used for making determination of all three gases, CO_2, CO and O_2, is some form of Orsat. This apparatus is easily used and sufficiently accurate for practical purposes; it does not give continuous readings, but by means of a gas collector an average sample over a period of time

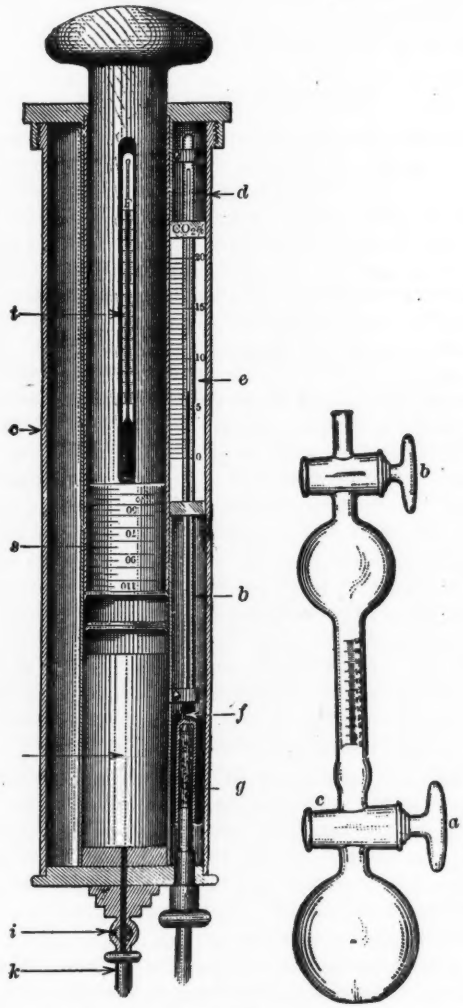


FIG. 3. CO_2 THERMOSCOPE

FIG. 4. POCKET SIZE CO_2 INSTRUMENT

can be collected and the average for the day or shift determined.

Essentially the Orsat apparatus consists of a measuring burette, three absorption pipettes, a leveling bottle, and a header, all of which are made of glass. The entire outfit is usually inclosed in a compact case for easy carrying about the plant.

Gas to be analyzed is drawn into the measuring burette by lowering the leveling bottle which had previously been filled with water and raised so that the burette was full of water. The burette is graduated into one hundredths so that it will give direct the percentage of the gas tested for. When the burette is full of the gas to be tested it is closed off from the source of supply by means of a pinch cock on a rubber connecting tube.

The absorption pipettes are U-shaped glass vessels and contain solutions for absorbing the three principal constituents of the flue gas. That nearest the burette contains potassium hydroxide solution for absorbing carbon dioxide; the second contains an alkaline solution of pyrogallic acid for absorbing oxygen; and the third contains ammoniacal solution of cuprous chloride for absorbing carbon monoxide.

One arm of the pipette which is connected to the header contains glass tubes or mineral wool or some other

POUNDS OF AIR USED PER POUND OF COMBUSTIBLE AS INDICATED BY CO_2 IN FLUE GASES

Per Cent of CO_2	Pounds of Air	Per Cent of CO_2	Pounds of Air	Per Cent of CO_2	Pounds of Air
21	12	14	18	7	36
20	12.6	13	19.4	6	42
19	13.3	12	21	5	50.5
18	14	11	22.9	4	63
17	14.8	10	25.2	3	84
16	15.7	9	28	2	126
15	16.8	8	31.5	1	210

porous substance which will give a greater wetted surface exposed to the gas when the solution is driven over into the other arm of the pipette by the gas being tested. The other arm of the pipette has a water seal or rubber bag attached to the top to prevent the deterioration of the solution by contact with the air.

By properly manipulating the pinch cocks and raising the leveling bottle, the gas from the burette is forced back and forth first between the burette and the first pipette which absorbs the carbon dioxide. After all the gas has passed into the pipette three or four times the

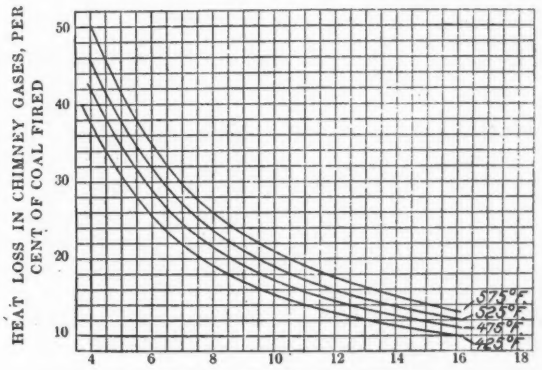


FIG. 5. RELATION BETWEEN PER CENT CO_2 IN FLUE GASES, STACK TEMPERATURE AND THE PERCENTAGE OF HEAT LOSS

water in the leveling glass is brought on a level with that in the burette and the reading on the graduated scale gives directly the percentage of carbon dioxide in the gas sample.

In like manner, the remaining gas is passed several times into the second pipette and the oxygen content is absorbed. The reading obtained on the scale after this absorption takes place is the CO_2 plus O_2 so the percentage of oxygen is obtained by subtracting the first

reading from the second. The carbon monoxide content is obtained in an exactly similar manner by passing the remaining gas into the third pipette.

For making determinations of carbon dioxide only another instrument working on a different principle has come into use in many power plants during the past few years. This instrument consists of an inclosed cast iron container partially filled with potassium hydroxide solution covered with a thin layer of oil as a seal. This container is airtight, but has connections by means of which the gas to be tested may be drawn through the space above the absorbing solution until a fair sample has been obtained in the container. The connections are then closed and the container shaken, mixing the gas and solution intimately, when the solution has become settled again, the absorption of the CO_2 from the gas has caused a partial vacuum to be formed, the amount of which is proportional to the percentage of CO_2 in the gases and is indicated by a vacuum gage calibrated to read in percentage direct.

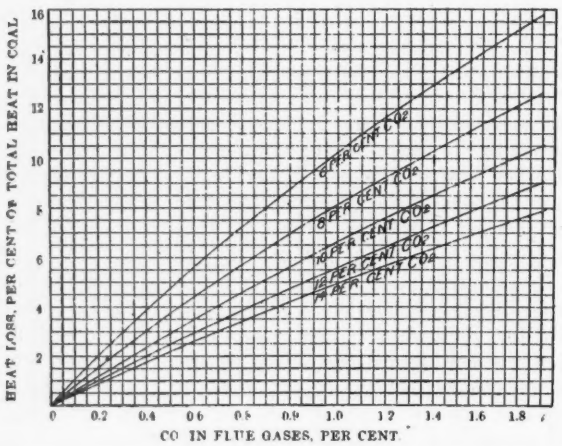


FIG. 6. RELATION BETWEEN PER CENT CO IN FLUE GASES, HEAT LOSS AND CO_2 PERCENTAGE

What is known as a CO_2 thermoscope depends upon the heat generated by a union of CO_2 and granular caustic alkali for its indication. A definite quantity of the flue gas is drawn through the cartridge containing the absorbing crystals; this cartridge is surrounded by a specially constructed thermometer which indicates the temperature rise due to the reaction which is proportional to the percentage of CO_2 in the gas being tested, so the scale is graduated to read in per cent direct.

Another CO_2 instrument of pocket size, shown in Fig. 4, depends upon the decreased volume caused by the absorption of the CO_2 from the gases to indicate the percentage. The lower bulb is filled with a solution of potassium hydrate, while the gas is drawn into the space above the cock *a*; the cock *b* is then closed and *a* opened and the solution allowed to run to the upper bulb by turning the instrument upside down; it is then turned right side up again and when the solution has come to rest cock *a* is closed and the instrument inverted in water and cock *b* is opened. By raising or lowering the instrument in the water, atmospheric pressure will be restored within the instrument when the level of the water in the instrument is in line with that outside, the scale on the stem of the instrument then reads the percentage of CO_2 in the sample.

Continuous recording and indicating CO_2 instruments are much more valuable to the operating force than those which give only "spot" readings but they are so varied in construction that a detailed description of the various types will not be given here. In several of these, the gases are automatically measured before and after the CO_2 has been absorbed and the difference indicated in per cent of shrinkage represents the percentage of CO_2 in the gas. In other types, a variation in the degree of vacuum in a suction line containing the absorbing solution is the principle upon which the indication of the per cent of CO_2 is based.

What CO_2 Readings Mean

It has been pointed out that a determination of the percentage of the CO_2 in the gases is of greatest importance. If combustion is complete there will be no CO in the gases; and when incomplete, CO will be formed and this condition is usually accompanied by the production of smoke. A visible indication of detrimental incomplete combustion is always present at the top of the stack, but analysis for CO_2 in the gases is the only method available for showing an excess of air. The accompanying table gives the pounds of air which have been used per pound of combustible as indicated by the percentage of CO_2 in the flue gases assuming complete combustion. The amount of air theoretically required to burn 1 lb. of carbon is 12 lb. and all above this is excess. Good practice calls for 50 per cent excess air, which will result in flue gases containing 14 per cent CO_2.

In Fig. 5 is shown how the heat loss in the chimney gases varies with the per cent of CO_2 and the difference in temperature between the flue gases and the air entering the furnace. And in Fig. 6 are curves showing the percentage of heat loss due to CO in the flue gases. In both of these sets of curves, it will be noted that the loss increases more rapidly at the low percentages of CO_2 than at the higher values.

High CO_2, say above 14 per cent, is likely to be accompanied by CO or incomplete combustion, caused chiefly by an insufficient amount of air to the furnace and leaky setting, or the furnace temperature may be too low due to poor design thus chilling the gases before they have time to unite with the air.

The proper percentage of CO_2 to be carried in any plant must be determined for that plant individually; it should, of course, be as high as possible without the presence of CO. Some plants may obtain 14 per cent or more with only occasional traces of CO while others show considerable incomplete combustion, as indicated by the presence of CO, when the CO_2 is as low as 8 per cent. Such a condition is caused when the boiler setting leaks badly around the back arch or in other places where the incoming air has no chance to mix thoroughly with the burning gases before they are chilled by the boiler heating surfaces. In the attempt to increase CO_2 percentage the fireman will naturally cut down the air supplied over the fuel bed, thus causing a greater percentage of CO along with the increase in CO_2. These cases, however, should be investigated thoroughly and the causes of such inefficiency remedied.

Using Low Grade Fuels

WITH rising prices of coal, a great deal of interest has been shown in the burning of what are considered low grade fuels commonly known as bone, culm, coke breeze, etc. With a better understanding of combustion, improvements in furnace design and better equipment for furnishing draft, much of this refuse has been made available for power plant use. Such fuel requires special handling in order that it can be burned at all, as it is likely to be high in ash and clinker forming material, as well as low in heat value, and contain a large percentage of moisture. A few specific cases of the use of these fuels will be described here to give an idea of how some of the problems have been successfully solved.

TABLE I. PROPORTIONS OF SOFT AND HARD COAL TO BE USED

		Soft. Per cent.	Hard. Per cent.
No. 1 Buck.....	Forced draft.....	30	70
	Natural draft.....	40	60
No. 2 Buck.....	Forced draft.....	40	60
	Natural draft.....	50	50
No. 3 Buck.....	Forced draft.....	50	50
	Natural draft.....	65	35
No. 4 Buck.....	Forced draft.....	65	35
	Natural draft.....	80	20

River Anthracite

IN THE early days of anthracite mining, only that part of the coal brought to the surface of the ground which was then of commercial value was shipped from the mines; coal dust and culm were dumped in piles outside the mines, on the banks of rivers and even in rivers in order that the refuse might be carried away cheaply. As a consequence, many of the river beds are covered with a foot or more of fine coal which goes by the name of river coal. It is taken from the bed of the river by means of grab buckets and loaded on barges for delivery to power plants. An analysis shows that it will run high in ash and moisture, but it dries out quite rapidly if left to stand in storage for a time. Its heat value runs between 12,000 and 12,500 B.t.u. per pound.

TABLE II. RELATION OF GRATE AREA TO HEATING SURFACE WITH ANTHRACITE

For No. 1 buckwheat, 1 to 40	For No. 3 buckwheat, 1 to 30
For No. 2 buckwheat, 1 to 35	For No. 4 buckwheat, 1 to 25

In one plant where this coal has been used successfully, horizontal, vertically baffled, water-tube boilers are installed, served by grates of the hand-fired dumping type which are placed in an inclined position, 4 ft. from the boiler tubes. In front of the grates in the furnace is a horizontal plate which serves as a hearth upon which the green coal is fired by dumping it from a hopper directly above the hearth and extending the width of the furnace. As the coal is not fed continuously, the hopper is provided with a gate by means of which varying amounts of coal at varying intervals may be discharged upon the hearth. The coal is allowed to lie on the hearth for a time until it has become thoroughly dried out and heated almost to the ignition point; it is then spread over the grates by a few thrusts of a wide hoe. Each of the furnaces is provided with two firing doors in the front wall beneath the hopper, and on either side of the hopper is a peek hole through which the condition of the fire may be seen. While the method of handling the fires is similar to that employed in hand firing, the labor is considerably less, the firing can be done much more evenly and the firing doors are not open so long as with a hand-fired furnace.

With forced draft, produced by an under grate blower automatically controlled by variations in the steam pressure, a depth of fuel bed from 4 to 12 in. can readily be maintained and under normal conditions the boilers are operated at 125 per cent of their rating; at peak loads, however, the boilers are forced to 200 per cent of their rating. The average evaporation per pound of coal as fired is 5 to 6 lb. of steam at a pressure of 125 lb.

Mixed Anthracite and Bituminous

TO BURN mixtures of anthracite and bituminous coals, a change in the design of the furnace is frequently necessary, particularly if the furnace was originally designed for anthracite. The object, of course, is to cut down the cost of fuel and the higher the proportion of the cheaper fuel that can be used to advantage, the greater will be the economy.

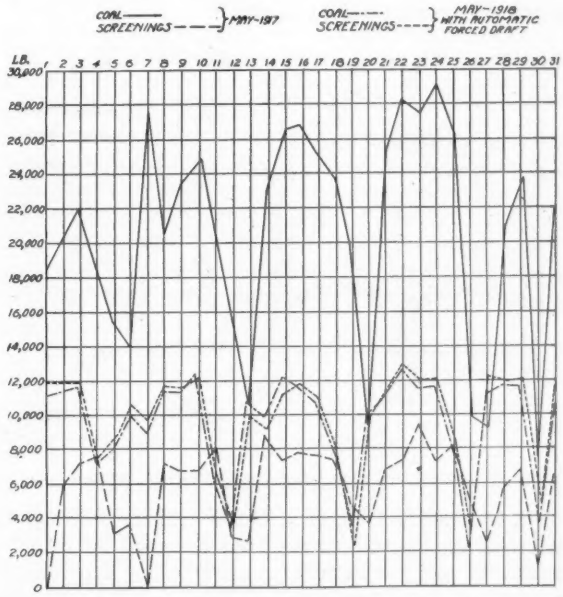


FIG. 1. AMOUNTS OF MIXED BITUMINOUS COAL AND ANTHRACITE SCREENINGS USED WITH AND WITHOUT FORCED DRAFT

Steam sizes of anthracite require greater draft through the fuel bed than does bituminous coal, but the latter requires more air over the fuel bed and greater combustion space. It is therefore much easier to go from bituminous to mixed fuel than from anthracite to a mixture of the two.

Ordinary furnace equipment designed for soft coal can burn anthracite buckwheat up to 20 per cent without any change of equipment. This is due to the fact that most bituminous furnaces are operated below their normal capacity.

When a greater percentage of anthracite, say 20 to 40 per cent, is mixed with the soft coal, it will be necessary in order to secure necessary capacity to supply forced draft under the grate. An air pressure of ½ to 2 in. of water in the ash pit will be required and this

can be supplied by an individual turbine blower or a steam jet. In either case, it should be under automatic control as a matter of economy.

If greater than 40 per cent of small anthracite is used, forced draft and buckwheat grates are required with an automatic system of draft control.

For hand-fired furnaces, Table I gives the various proportions of different sizes of anthracite that can be used with forced and natural draft, and Table II gives the relation of grate area to heating surface which has proved practicable. The sizes of the holes in the grates vary from ⅛ up to 5/16 in. in diameter, depending upon the size of coal used and the percentage of air space in manufactured grates runs from 3 to 30 per cent.

As an example of how the addition of forced draft can be used to increase the percentage of anthracite screenings, a report from a New England factory states that 25 per cent screenings were burned with soft coal under a 72-in. boiler with natural draft; by the addition of automatically controlled under grate blowers and grates with ½-in. air spaces the percentage of the cheap anthracite screenings was increased to 50 per cent, as is shown in Fig. 1, and the load maintained was the same as with the higher priced mixture.

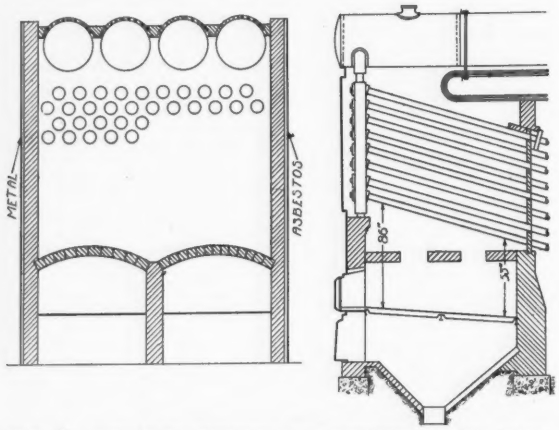


FIG. 2. FURNACE DESIGNED FOR BURNING MIXED COAL

In a city plant where a smoke ordinance is rigidly enforced, the original furnace was designed for burning anthracite but the increasing price led to experiments with mixed No. 3 buckwheat anthracite and bituminous slack. Arches were built over the fuel bed as shown in Fig. 2, but otherwise the equipment was unchanged, as forced draft fans and anthracite grates were already installed. The ratio of grate to heating surface is 1 to 47½ and the air space through the grates varies under the different boilers from 9 to 20 per cent. Under normal conditions, full load rating is maintained on the boilers; but during peak periods, the load runs up to 150 per cent of the factory rating.

Under test conditions, highest evaporation per pound of fuel was secured when 7½ per cent of bituminous was used, the result being 13 lb. of steam from and at 212 deg. This mixture has a heat value of 12,500 B.t.u. per pound and gives smokeless combustion when properly handled.

There are three fire doors to each furnace, making six to each boiler which is rated at 900 hp. The method of firing employed is to cover the entire grate surface with a thin layer of coal each time the fire is replenished, which is done just after the coal has reached the incandescent state. As soon as the fuel has become ignited, a light rake is used to level the bed and cover up any holes that may have developed. When the bed of coals and ashes has reached a thickness of 8 to 9 in., the ashes are dumped, which occurs about twice in 24 hr.

An air pressure of 3 to 4 in. of water is carried in the ashpit, the drop through the fuel bed is 1.76 in. and the rate of combustion averages about 35 lb. per sq. ft. of grate surface.

LIGNITE

PROBABLY the most authentic tests conducted with lignite as fuel have been made by the U. S. Bureau of Mines and, based upon these tests, the furnace designs shown in Fig. 3 have been suggested. North Dakota

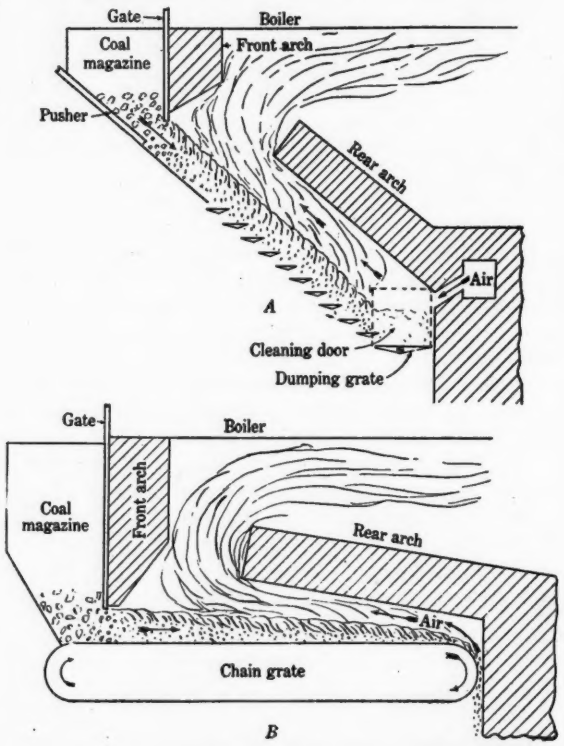


FIG. 3. BOILER FURNACE DESIGNS SUGGESTED FOR BURNING LIGNITE

lignite cracks and crumbles easily when heated in the fire which increases the resistance of the fuel bed to the flow of air, so that high draft is required to produce moderate rates of combustion. The crumbling also causes intense combustion near the grate where the air enters the fuel bed which results in the fusion of the ash into clinker. In the ordinary hand-fired furnace this clinker is hard to remove without spoiling the fire and shaking much of the fine, disintegrated lignite into the ash pit.

Lignite burns with a clear yellow flame almost free from soot and is very nearly a smokeless fuel. The drawbacks in burning it are: Difficult ignition, disintegration in the fire, high resistance to flow of air through the fuel bed, sifting of combustible through the

grate, and clinkering. The furnace designed for its use must therefore provide for rapid ignition, plenty of air through the fuel bed, and means for preventing sifting and cleaning without spoiling the fire.

These requirements were taken into consideration in the suggested designs shown. With the inclined step grate boiler furnace the fuel can be fed down the grate by gravity aided by hand regulation or it can be pushed out of the magazine mechanically. The horizontal air spaces between the step-grate bars can be kept open by a hand poker or by rocking grate bars. Clinker, as it accumulates on the dumping grate, can be removed through side cleaning doors or dumped to the ash pit. Fine ash accumulation on the dumping grate can be removed by shaking or dumping. Air will be admitted through the openings between the step-grate bars and through the special openings at the end of the grate.

Probably two-thirds or three-fourths of the air needed for combustion should be admitted over the fuel bed at the end of the grate, so that as the air passes between the fuel bed and the arch, it will scrub the surface of the fuel bed and burn the fuel. The comparatively low resistance to the entrance of air at the end of the grate and the high resistance through the fuel bed could be so adjusted as to give proper combustion without forced draft.

Similar principles, it will be observed, are used in the design of the chain-grate type of stoker illustrated, but it is thought that the surface of the grate should be inclined at about 30 deg. to the horizontal instead of being horizontal as illustrated.

The temperature in a furnace burning lignite will not exceed 2200 deg. F. with carbon dioxide content in the gases as high as 13 to 14 per cent, so little difficulty should be encountered in securing material for the arches.

It is probable that the two types of furnaces suggested here can be used for low grade fuels other than lignite which are difficult to ignite.

Coke Breeze

This is screenings or refuse from coke ovens or gas plants left after the pea size has been taken out. It is not a low grade fuel in the sense that it is low in heat value for it contains from 11,000 to 14,400 B.t.u. per pound depending largely upon the coal from which it was made. It is regarded low grade simply because of its low market value.

With this fuel it is necessary that a very thin bed of fuel be maintained or that forced draft be employed, as it is so fine that it offers high resistance to the air passing through the fuel bed. Being principally the fixed carbon and ash of coal, it burns slowly and therefore requires a larger grate surface, by about 50 per cent, than that required for bituminous coal. The type of grates to be used and the furnaces are similar in all respects to those suitable for anthracite. Special types of chain grates equipped with non-sifting links and a method of distributing forced draft to the different zones of the grate have worked very successfully when burning coke breeze.

Mixed about half and half with bituminous coal, coke breeze is used in the boiler furnaces of a coke plant with good results. In this case, a larger proportion of the coke breeze would be used, but it is not available. Sprinkling type stokers are employed with forced draft created by a steam jet applied under the grates, which are of the shaking and dumping type.

Using Waste Fuels

The Utilization of the Waste Products of Yesterday for Steam Generating Purposes

THE TERM waste fuel is usually employed to denote certain combustibles the production of which is more or less in the nature of a by-product. The term, however, is ambiguous to a certain extent and it is often difficult to decide which are to be classified as waste fuels and which are not, depending upon their nature, their availability and their value as a fuel with reference to a more standard fuel such as coal or oil. By-product fuels would be a more suitable term under which to classify them since their production is nearly always associated with the manufacture or production of some other and generally more important material. It is evident, of course, that as the value of the waste or by-product fuel increases with reference to the material of which it is a by-product, its significance as a waste fuel decreases. Therefore, as soon as the value of the by-product fuel exceeds that of the primary product it relinquishes its position under the classification of waste fuels as well as by-product fuels. The term waste fuel, no doubt, arose from the fact, that certain by-products which had previously gone to waste were finally recovered and used as fuel with a consequent increase in profits. From this viewpoint the term waste fuel may have been correct, but as a matter of fact, in many instances, these by-products should never have gone to waste in the first place. They should have been recovered and utilized from the beginning.

As an excellent example of a case of this kind may be cited the recovery of the so-called waste gases from coke ovens. The old beehive coke oven which was used everywhere throughout the United States and which is still used to a great extent, is a device of sin, which permits not only the valuable coal tars to run to waste but discharges all the gases into the atmosphere through a hole in the top of the structure. Until the advent of the modern by-product coke oven this wasteful procedure continued for years. To be sure, the gases were referred to as waste gases, since they were wasted—gloriously wasted. The by-product oven conserves what was formerly allowed to befoul air or land or stream, the gases being used either as an illuminant, as fuel in internal combustion engines or as fuel in the furnace under the boiler. At first, these gases were still referred to as waste gases, but as time went on their high value became more and more manifest, until now they are usually called by-product gases. There never was any justifica-

tion in allowing these gases to go to waste and the mere fact that they did, does not make them waste gases.

In a like manner, a number of other industries are now using certain by-products for fuel which formerly were wasted. These fuels are of high value and are now not referred to as waste fuels, because their use has increased the efficiency of the plant. If such by-product fuels can not be used economically then they are truly waste fuels.

In other words it is the cost of burning by-product fuels as compared to the cost of burning standard fuels which determines whether a certain material is to be classed as a waste fuel or not. For instance, if, in a plant where a certain by-product is available as fuel, it is found that coal or oil can be bought and burned for less than the expenditure involved in handling and burning the by-product, then the by-product may be said to be a waste fuel. Since the by-product, under these conditions, has no practical value as fuel, and since it is the purpose of this article to discuss only such fuels as are of practical value, it will be seen that we are not interested in waste fuels, but rather in by-product fuels.

By-product fuels may be either solids, liquids or gases. The gaseous by-product fuels are probably the most common and their recovery and use is so universal that they are more properly discussed under the heading of Special Fuels. Liquid by-product fuels are used to a greater extent in Europe than America owing to the higher price of coal in the former. Creosote oil has long been burned under steam boilers in Germany and in England mixtures of pitch and tar oil have been successfully used as boiler fuel. Solid waste fuels have been burned to a small extent, in both Europe and America, but their utilization on anything approaching a practical commercial scale is of recent origin. Among the latter may be enumerated, wood wastes, sawmill refuse, bagasse, straw, anthracite silt, culm, dust, coke breeze, etc. Most of these were essentially wastes until the recent increase in price of coal and oil made their recovery an economical proposition. Coke breeze, a material which was formerly discarded or used only for filling, is now being used for steam making, owing not only to the increase in fuel cost, but also to new developments in stoking machinery.

Wood Waste

IN CERTAIN localities where wood wastes were available in large quantities and in many wood working plants, sawdust, slabs and shavings have been burned for a long time, more for the purpose of getting rid of the refuse than for its value as fuel. In many localities sawmill refuse was burned promiscuously without any attempt to convert the heat units into power. It was, and still is, actually burned at an expense to the producers. Due to the present high price of standard fuels, however, these waste products have a marketable value and can be used to advantage under the boiler as fuel. Especially in the Northwestern part of the United States where there is an abundance of sawmill refuse available, there is a decided tendency towards the use of this fuel. In some districts cordwood may be used to advantage in power plants.

Wood waste is produced in a number of forms, such as sawdust, shavings, slabs, blocks and edgings. Sawmill refuse contains wood of every kind and size from fine sawdust to blocks of wood as large as a 12-in. cube. This diversity of sizes, however, is desirable since it is doubtful whether satisfactory operation of furnaces could be secured with either of these extreme sizes alone. Sawdust when burned alone and especially when it is moist, is more or less troublesome to burn owing to the difficulty of supplying the requisite amount of air. The large blocks, if burned alone, would tend to burn with an excess of air. In any case, however, the furnace should be designed for the fuel to be handled.

In order to produce a more uniform size fuel and one which is also more easily handled, many mills hog the slabs and sticks. By putting this fuel through the hog, it is converted into flat chips about three inches long. This, together with sawdusts of various sizes and shavings from planers makes a very desirable form of fuel.

Wood waste of the type described is composed of a great variety of woods. These woods are very similar in some respects but there is a great variation in some of their characteristics, particularly as regards the moisture content. Table I, compiled by Darrah Corbet, gives a list of the principal woods available in different parts of the country and their approximate moisture content as ordinarily received as fuel from the sawmills.

TABLE I. CHARACTERISTICS OF PRINCIPAL SAWMILL REFUSE FUELS

NAME of WOOD	LOCATION	PER CENT MOISTURE	FUEL CHARACTERISTICS
Birch	Michigan	40 to 45	Fair burning
Cedar	Western Washington, Oregon and British Columbia	45 to 55	Fair
Cedar	Central California	40 to 50	Fair
Cypress	Florida, Texas, Mississippi	35 to 54	Fair
Fir	Washington, Oregon, British Columbia	35 to 45	Good
Fir	Central California	35 to 50	Poor
Hemlock	Washington, Oregon, British Columbia	40 to 50	Poor
Hemlock	Michigan	45 to 55	Poor burning
Maple	Michigan	40 to 55	Fair
Pine-Cork	Eastern Washington, Idaho	35 to 45	Fair
Pine long leaf	Florida and Gulf Coast	40 to 50	Fair burning
Pine short leaf	Florida and Gulf Coast	40 to 50	Fair burning
Pine short leaf	Florida and Gulf Coast	20 to 40	Fair burning
Pine White	Mexico	45 to 55	Fair burning
Pine White	California	30 to 45	Fair burning
Pine Sugar	California	40 to 65	Poor
Pine Yellow	Central California	40 to 45	Fair
Redwood	California	45 to 50	Poor

Regarding wood from its ultimate composition, we may express it as a hydrate of carbon, that is, as carbon united to water, the proportion of hydrogen and oxygen being nearly the same as in water. But regarded from its proximate composition, it is entirely different. Woods having similar ultimate compositions behave differently in distillation in a closed retort and produce very different proportions of carbon (as charcoal) hydrocarbons, acid products, etc. Hard wood, contrary to general supposition, gives less heat than soft wood. According to Gottlieb's experiments, pine wood has a heating value of 5000 calories, while oak gave only 4620 calories.

The dry non-resinous woods give off practically the same amount of heat in burning. This averages about 8500 B,t.u. per lb. The fuel value of woods varies considerably with the amount of resin present. This is evident when it is considered that the calorific value of resin is about twice that of wood. The curve shown in Fig. 1 illustrates graphically the variation of the fuel value of wood with resin content.

The non-resinous woods as indicated by an ultimate analysis contain about 50 per cent of carbon and the other 50 per cent is mainly hydrogen and oxygen in such proportions as to burn to water. Table II gives an analysis of some of the more common woods and their heating value expressed in B.t.u.

Ordinary hog fuel varies in B.t.u. content according to the proportion and the kinds of wood of which it is composed. On an average, however, it runs about 8600 B.t.u. per lb. of dry fuel. Sawmill refuse also varies considerably in heating value and, as received from the mills, in moisture content. Sawdust, particularly in mills where water is kept running on the band saws to keep them cool, may also contain large amounts of moisture.

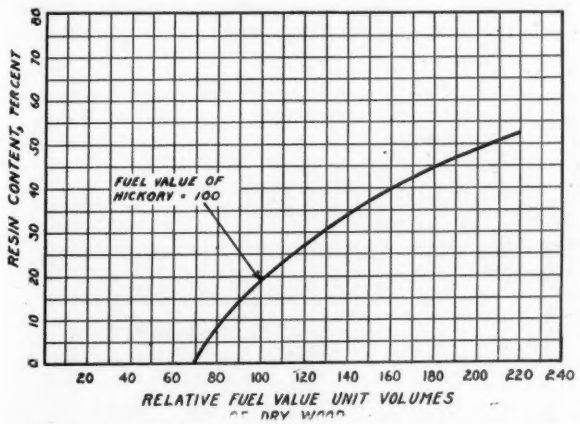


FIG. 1. APPROXIMATE RELATIVE FUEL VALUE OF LONG LEAF PINE CONTAINING DIFFERENT AMOUNTS OF RESIN, COMPARED WITH HICKORY

It will be evident, of course, that it is desirable to have the wood fuel as dry as possible before feeding it to the furnace. If the wood has been well dried we may regard 1 lb. of it as equivalent to 0.4 lb. of bituminous coal; or, in other words 2.5 lb. of wood are equivalent to 1 lb. of coal.

Handling Wood Fuel

Perhaps one of the principal reasons why wood waste has not been used as fuel on a more extensive scale, is the difficulty of transporting and storing it. Naturally, it is very bulky, and on account of the varying characteristics, some of which have been described in the foregoing, it is difficult to handle. It is difficult to load a vehicle with a sufficient amount to secure an economical load. Special bodies are sometimes fitted to railway cars, in order to accommodate a sufficient volume of fuel. On account of these loading limitations, it is obvious that it is not economical to transport this fuel over long distances and at present it is rarely moved over a hundred miles. Its value is most fully realized when burned at the plant or mill where it is produced.

While sawmill refuse may be stored, it is difficult to remove the fuel from storage when it becomes necessary to use it, especially after having been in storage for some time. It usually settles into a hard compact mass at the bottom and some mechanical means should be provided to loosen the fuel. At the plant of the Portland Railway Light and Power Co., where there is a hog fuel storage containing about 2,400,000 cu. ft. of fuel, large rakes are employed, not only for the purpose of loosening the fuel, but also to remove it as it accumulates under the conveyor. These rakes are operated by a hoist and donkey engine.

Furnace Design and Operation.

As might be expected, furnace design for wood burning installations will vary according to the character of the fuel burned. The results obtained, however, with any wood burning furnace, depend to a great extent upon the care and attention given it. Contrary to a general belief, it requires as much careful thought and attention in the fireroom to burn wood successfully as it does to burn any other fuel.

TABLE II. ANALYSIS AND HEAT VALUE OF VARIOUS WOODS

	Per cent Carbon	Per cent Hydrogen	Per cent Oxygen	Per cent Nitrogen	Per cent Ash	B.T.U. per lb.
Ash	49.18	6.27	43.91	0.07	0.57	8480
Beech	49.06	6.11	44.17	0.09	0.57	8591
Elm	48.89	6.20	44.25	0.16	0.50	8510
Oak	50.16	6.02	43.36	0.09	0.37	8316
Fir	50.36	5.92	43.39	0.05	0.28	9063
Pine	50.31	6.20	43.08	0.04	0.37	9153

For good results with return tubular boilers, the shell should be located at least 48 in. and preferably 58 to 60 in. above the grates. For water-tube boilers a distance of 6 to 8 ft. from the grates to the bottom row of tubes will give good results. Bridge walls should not be built closer than 14 in. to the shell, in the case of return tubular boilers, and often 16 in. is better. With water-tube boilers, the bridge wall construction is more or less dependent upon the make of boilers.

While the standard type of furnace used in connection with coal-fired installations will give good results in burning shavings and sawdust, it will be found that the dutch oven furnace is best adapted for this fuel. For feeding the fuel to the furnace, an excellent arrangement may be secured by introducing the fuel in a more or less continuous stream through a hole in the top of the furnace, and allowing it to pile up in a cone on the grates. This method is entirely satisfactory and requires very little labor, one man being able to take care of several thousand horsepower. An installation of this type is shown in Fig. 2. The furnace which is of a somewhat modified form of dutch oven is placed below the floor of the boiler room and is fitted with grates, ash pit, and bridgewall similar to those used in connection with ordinary hand fired furnaces. Two downspouts are provided for feeding the wood, the greater portion of which is burned in suspension. That not completely consumed falls on the grate where it piles up in the form of a cone and is gradually burned. Fuel is conveyed to the downspouts by a screw conveyor.

With this method of feeding fuel in a continuous

manner, it is obvious that in order to expose the greatest possible amount of surface of the cone for burning and yet prevent excessive infiltration of air through the grates, each fuel pile should cover practically a square section of grate.

Another system employing the same type of dutch oven furnace as the system just described, and which gives very satisfactory service, is to concentrate all of the fuel in a reinforced concrete fuel house, run a sawdust chain through the floor of this fuel house and over the top of the dutch oven furnace at a height of about

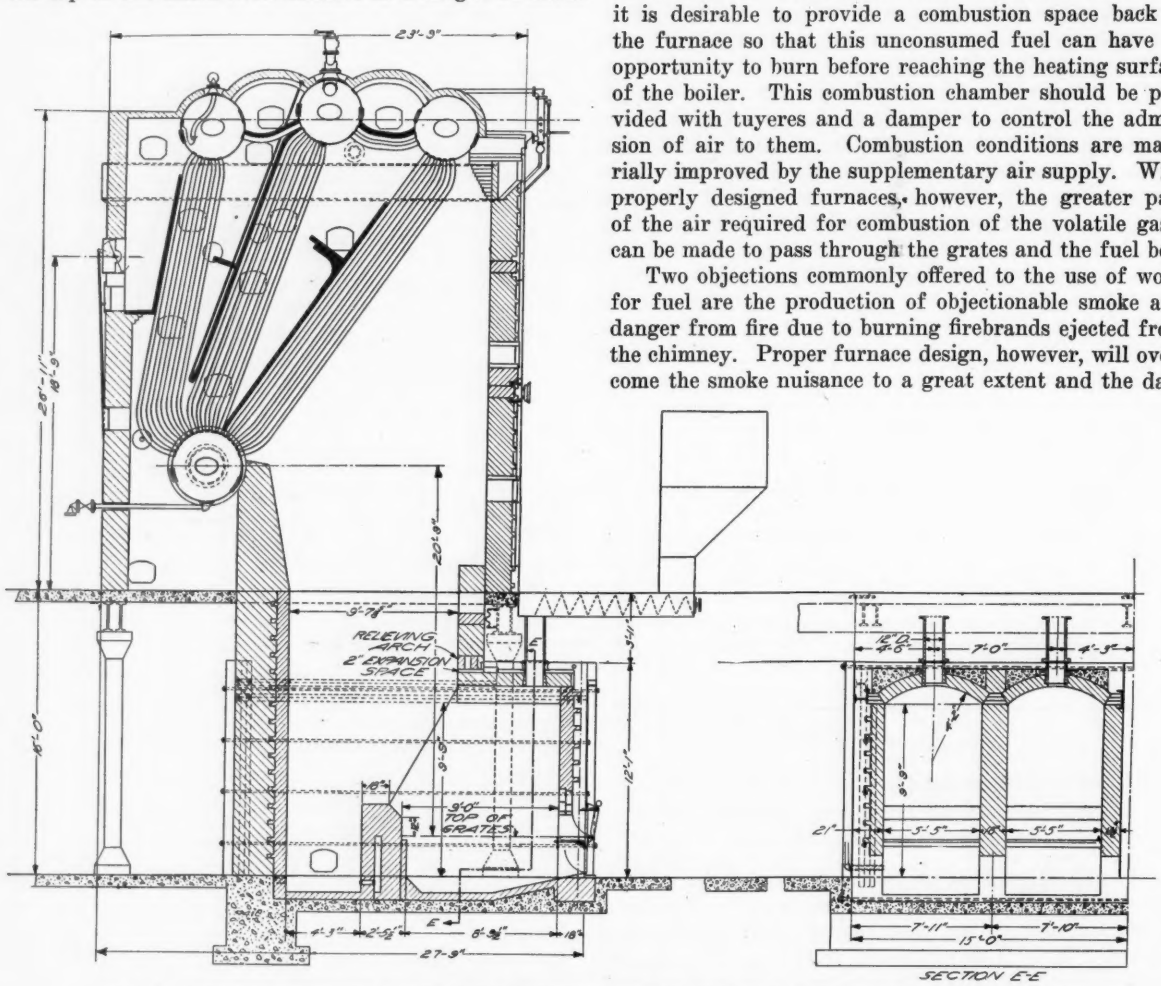


FIG. 2. SECTION THROUGH LARGE WOOD BURNING BOILER SHOWING DESIGN AND FUEL CONVEYOR

7 ft. This chain will run in a trough all the way; in the fuel house equip this trough with a sliding cover so that the amount of fuel to the chain may be regulated. Above the furnace, the trough is equipped with downspouts which feed fuel through holes in the top of the furnace.

High temperatures are desirable for burning wood wastes and to attain this condition, it is advisable to run the bridgewall up to such an extent as will give the desired temperatures without interfering materially with the draft. The furnace should be surrounded on the top and the sides with incandescent fire brick since the reflected heat aids in the combustion of the fuel and the evaporation of the moisture present. It has been shown that for any type fuel, furnace temperatures can be varied by changing the area through the throat of the furnace. According to Darrah Corbet, the area of the throat for wood burning furnaces, in general, should be from 6 to 14 sq. in. per rated boiler horsepower, depending upon fuel conditions, design of furnace, rating which is to be expected and the available draft.

Since wood contains a large percentage of volatile matter which will naturally be distilled off quickly in a hot furnace and since much of the finer fuel is quickly carried out of the furnace with the force of the draft, it is desirable to provide a combustion space back of the furnace so that this unconsumed fuel can have an opportunity to burn before reaching the heating surface of the boiler. This combustion chamber should be provided with tuyeres and a damper to control the admission of air to them. Combustion conditions are materially improved by the supplementary air supply. With properly designed furnaces, however, the greater part of the air required for combustion of the volatile gases can be made to pass through the grates and the fuel bed.

Two objections commonly offered to the use of wood for fuel are the production of objectionable smoke and danger from fire due to burning firebrands ejected from the chimney. Proper furnace design, however, will overcome the smoke nuisance to a great extent and the danger of sparks from the chimney can be reduced by using screens around the top of the chimney.

Bagasse as a Fuel

A FORM OF waste or by-product fuel which is available in considerable quantities in sugar mills and which has been used under the boilers at these mills for steam generating purposes is commonly known as bagasse. This consists of crushed sugar cane and results from the process of extracting the juices from the green cane. Chemically, bagasse consists mainly of a tough fiber, sugar or sucrose, glucose, and water. The fiber content ranges from 30 to 50 per cent; the sucrose

from almost nothing to 10 per cent and the water content from 40 to 65 per cent. Its composition, however, varies according to the method and effectiveness of milling, good milling resulting in a bagasse low in moisture content, and therefore, very suitable for burning.

By experiments conducted by Dr. Nanis, the heating value of moisture-free bagasse was found to be 8100 B.t.u. per lb. This high thermal value is not obtained in practice, however, due to the high moisture content of bagasse as it is generally delivered to the furnaces. Knowing the moisture content, the fuel value of bagasse may be found by calculation. The following method given by Prof. Kerr is in general use.

Suppose we have a bagasse containing 51 per cent moisture, and that this is to be burned in a furnace the stack temperature of which is 550 deg. F. Assuming the heat value of 1 lb. of moisture-free bagasse to be 8100 B.t.u. the heat value of the dry matter in the bagasse is $(100 - 51) \times 8100 = 3969$ B.t.u. Assume the temperature of the bagasse as it enters the furnace to be 75 deg. F. The water in the bagasse will then have to be raised from 75 deg. up to its boiler point (212 deg. F.) and then vaporized before the bagasse can be completely burned. The calculation for the heat necessary to vaporize this water is as follows:

Heat necessary to raise water in 1 lb. of bagasse to boiling point $= 0.51 \times (212 - 75) = 69.87$ B.t.u.

Heat necessary to vaporize the water in 1 lb. of bagasse from and at 212 deg. F. $= 0.51 \times 970 = 494.7$ B.t.u.

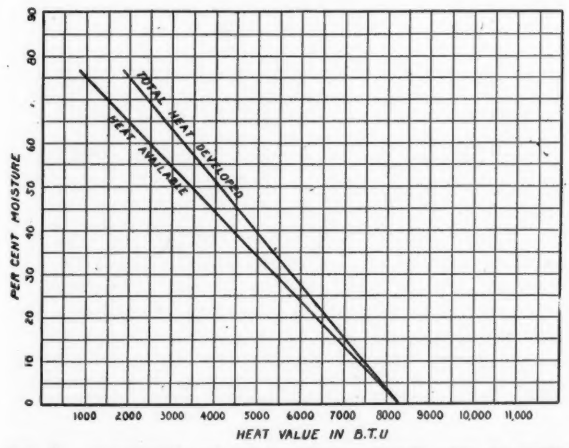


FIG. 1. VARIATION OF HEAT VALUE WITH THE MOISTURE CONTENT OF BAGASSE

Heat necessary to superheat vapor from 212 deg. to 550 deg. $= 0.51 \times (550 - 212) \times 0.47 = 81$. B.t.u. when 0.47 is the specific heat of superheated steam.

Heat lost in the water $= 69.87 + 494.7 + 81 = 645.57$ B.t.u.

Net heating value of 1 lb. of bagasse containing 51 per cent moisture $= 3969 - 645.57 = 3323.43$ B.t.u.

This result makes it obvious that one of the most important factors in the burning of bagasse is to use the fuel as dry as possible. At first, little attention was paid to this feature and it was the custom either to sun dry it, or to feed it to the furnace in a wet condition. Now, however, a number of methods have been developed to dry it partially before delivering to the furnace. A description of the various driers would require more space than it is possible to devote to this phase of the subject, but most of these devices utilize the heat of the furnace gases in some way. Unquestionably, great economies can be effected by drying this fuel first and in some cases where about 15 per cent of the moisture present was removed in this manner, the fuel had a heating value of 55 per cent greater than the wet bagasse. This is equivalent to a saving of 2½ gal. of oil per ton of cane ground. The chart shown in Fig. 1 illustrates the relation between heat value and moisture content in bagasse.

Boilers and Furnace Design

Bagasse fired boilers may be of either water-tube or fire-tube type and need not be different from those used with other fuels. The type of boiler used is of

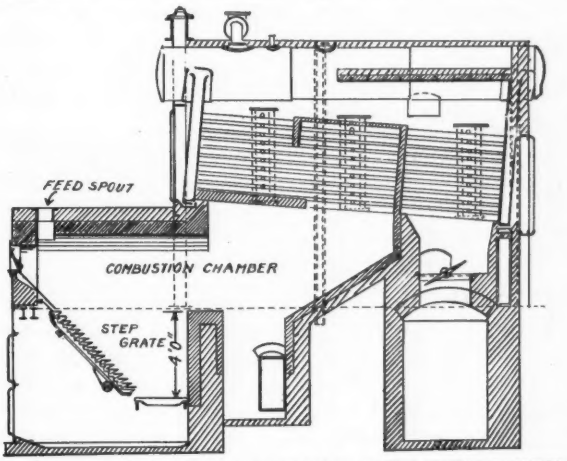


FIG. 2. STEP GRATE BAGASSE FURNACE WITH UNDERGROUND SMOKE FLUE

little importance since almost any type can be used successfully. The important part of an installation using this fuel is the furnace, and upon this depends the success or failure of operation.

The large amount of moisture in the fuel calls for larger flues and stacks than is the case with coal. Under proper conditions a pound of green bagasse should evaporate from 2 to 2.5 lb. of water from a feed temperature of 100 deg. and at 90 lb. pressure.

Although bagasse contains a large amount of air, when burned on a small grate surface with a high rate of combustion it requires a high draft. When it is burned in furnaces having a large combustion chamber, however, air in most cases is supplied in great excess. Natural draft furnaces will run about 1 sq. ft. of grate surface for each 165 lb. of water evaporated per hour, while forced draft furnaces will work well with 1 sq. ft. of grate to 540 lb. of water per hour.

The step grade furnace shown in Fig. 2 is a construction which has proved very successful and is used in the Hawaiian Islands. The ordinary dutch oven type of furnace will give good results, however, and is much used in this country. The design varies somewhat from the ordinary type of dutch oven furnace. The furnace is much higher, usually from 8 to 11 ft., from the top of the grates to crown of arch. Semi-circular arches are preferred and a rather high bridge wall is used, about 4 ft. above the grates.

Rates of combustion with this fuel vary between 85 and 225 lb. of bagasse per hr. per sq. ft. of grate surface. As a general rule, the amount of grate surface should be small in order to prevent high excess air losses. The grate area will vary somewhat with the amount of moisture in the fuel, a dry fuel requiring less grate surface than a fuel containing a high percentage of moisture. The design of the grate bars will depend upon the nature of the bagasse fired. The finer grades of bagasse such as are produced by the more modern mills require a closer spacing of grate bars than the coarse grades. The minimum spacing, however, is about a half inch, since sufficient space must be allowed for the insertion of a poker for cleaning.

Bagasse, like wood, contains a considerable amount of volatile matter, which is distilled off at comparatively low temperatures. It is, therefore, advisable to supply a certain amount of air above the fuel bed, for the proper combustion of these gases. This air supply should be under control by means of dampers and should be heated before entering the furnace.

If too little air is supplied in this manner, dense volumes of smoke will be produced and the heat value of the volatile gases will be lost.

Burning Mine Refuse

THE MINING of coal, especially anthracite, is usually accompanied by the production of a considerable amount of waste material, known as mine refuse. This, as well as the proportion of fuel left in the mines and which is not worth bringing to the surface, has a certain heating value and if properly burned under the boilers of steam generating plants would be of material assistance in conserving our coal supply.

As long as the cost of coal, labor and transportation was low, there was no apparent necessity for using this refuse and it, therefore, possessed no marketable value. Consequently, it was used only for back filling in abandoned mines or was brought to the surface where it was piled up around the mouth of the mine. Throughout many years these dumps or culm banks grew steadily until many of them resembled small mountains. Today, with the cost of the three items listed above greatly increased, the dumps of culm and other washery refuse are decreasing in size rapidly. Quality plays a relatively small part in setting the cost of coal today, and this has resulted in cutting down the growth of the refuse dumps at the mines, and of putting much of the old material under boilers.

It will be obvious that owing to the high percentage of incombustible matter in this material it is not economical to transport it far from the mining centers where it is produced. The place to burn it is, therefore, in the vicinity of the mines where it is produced, but within a certain limited radius of, say 5 to 20 miles, it can be used to advantage. Culm and washery refuse when burned properly forms a valuable cheap fuel for power generation. Furthermore, when it is considered that for each 8 or 9 tons of anthracite coal produced about one ton of coal is consumed at the mines for the production of steam, the reasons for using this mine refuse for the production of power, light and heat are evident. In this manner, by-products of from 11,000 to 12,000 B.t.u. per lb. can be made to relieve from 85 to 90 per cent of the commercial sized anthracite which has been consumed for steam generation at the mines and at industrial plants near the mines.

Burning Culm

THE FINE material which is known as culm, slush, or silt contains about 70 to 80 per cent of combustible matter and is therefore a good fuel provided proper means of burning can be used.

Probably the best method of utilizing such fuel is to mix it with bituminous coal and to burn it on ordinary grates. A number of tests with various mixtures of culm and different kinds of bituminous indicate that the mixtures of culm and caking bituminous coals give best results. The reason why caking coal is better adapted to mix with culm lies in the fact that the caking coal fuses at a comparatively low temperature and the fusion takes up the particles of culm, forming a homogeneous mass of fuel which burns uniformly. Results of the tests referred to above show that a mixture consisting of 30 per cent culm and 70 per cent caking bituminous coal produce a water evaporation equal to that afforded by the straight bituminous coal.

Such a mixture of bituminous and culm is easier to burn than soft coal alone, and produces little smoke. When bituminous alone is burned, the fuel bed becomes a hard, caked mass which requires considerable poking to effect combustion. With the mixture, this hard caking of the fuel bed does not occur and the fuel is more easily handled by the fireman.

The smaller the particles of culm, the greater will be the amount of bituminous required. The amount of bituminous necessary also depends upon the thoroughness of mixture; the better the mixture, the better the economy.

When burning dust and culm considerable difficulty may be encountered with the formation of soot on the heating surfaces. This is due to the high drafts necessary. As the fuel is shoveled into the furnace a certain amount of the finer coal particles and dust is burned in suspension or is brought over to the rear connections in the form of coke. Due to the greater draft necessary, the higher the rating the larger will be the soot deposits. In certain installations, an analysis of this soot at times shows a slightly higher calorific value than the coal from which it was made. Attempts to burn this soot proved unsuccessful, but it is probable that it could be briquetted successfully.

It is advisable to carry as thin a fire as possible without danger of blowing through. A good bottom of from 3 to 5 in. thick is necessary upon which to build, and under ordinary conditions a fuel bed of 16 to 18 in. will be maximum. The average thickness will be about 6 to 8 in.

Another difficulty which must be met in burning the finer sizes of anthracite wastes is the tendency of the draft to blow the fine particles from the grate surface. This is especially so when using chain grate stokers and a modified form of grate is desirable. Another method of overcoming this difficulty is to equip the furnace with pin hole dead plates and to cut off some of the air supply through the grates, the air being supplied through the holes in the dead plates instead. This will produce a

more even fire and would reduce the open spaces in the coal bed caused by the blowing away of particles.

Burning Slack Coal

Slack coal containing a high moisture content is found to be unsuitable for use in an ordinary furnace. Unless special provisions are incorporated in the design of the furnace, the coal will fail to ignite until it has passed into the furnace for a distance of about 3 ft. on chain grate stokers. This is due to the excessive moisture content of such coal, which in some cases runs as high as 20 per cent.

This fuel, however, contains a considerable amount of combustible matter and the heating value averages about 10,000 to 11,000 B.t.u. per lb. In burning this coal it has been found that some arrangement is necessary whereby the moisture is evaporated as soon as the fuel reaches the furnace grate. This may be accomplished by building an arch over the entire area of the grate except for a short opening near the front of the furnace which serves as a gas passage. Such an arch will deflect the flame from the burning coal down upon the incoming green coal, evaporating the moisture and igniting the coal.

Utilization of Waste Heat

THE GENERATION of steam by utilizing the heat in waste gases from various industrial processes will, with properly designed equipment, effect great economies and will insure a substantial return on the investment. Gases from various industrial processes usually contain a considerable amount of heat, and with a suitable waste heat boiler installation from 35 to 80 per cent of this heat may be recovered. It is, therefore, desirable to utilize waste heat in this manner not only from an economic standpoint but also as a measure of conservation of our national resources. A well designed installation will pay from 25 to 70 per cent on the total investment in one year.

The designs of early waste heat boilers were all based on the theory of non-interference of operation of the primary furnaces. Designers assumed that the draft could in no way be impaired and as a consequence designed their boilers with large gas passages and without baffles in order to reduce the frictional resistance of the gases. The gases were given a straight path through the boiler and no attempt was made to increase the capacity of the primary furnace.

Such boilers were considered practicable only with high temperatures, approaching those of coal fired practice. This of course limited their use to connection with a few industries only and as a result progress in this field of engineering was not as rapid as might have been desirable.

A better understanding regarding the theory and the laws of heat transfer and the function of gas velocity has resulted in radical improvements in design and today the waste heat boiler is being successfully used in connection with a dozen or more industries. Their use has been common in the cement industry for a number of years and waste heat boilers have come to be regarded, more or less, as standard equipment in cement plants. Other industries using waste heat boilers are given as follows:

Open hearth steel furnaces; bee-hive coke ovens; heating furnaces; copper refining furnaces; zinc and nickel refining furnaces; oil stills.

Principles of Design

Gas velocity has been shown to be a determining factor governing the successful operation of waste heat boilers. Rate of heat transfer is dependent upon gas velocity and the difference in temperature between the gas and the absorbing surface, but the effect of the latter is small as compared to that of increased gas velocity.

Where the temperature of the gases is less than 1800 deg. F. the area of gas passages through the boiler should be decreased so as to obtain an increase in gas velocity. The necessity for high gas velocities may be appreciated by comparing the operation of the waste heat boiler against that of the direct fired boiler. In coal fired furnaces the temperature is generally about 2700 deg. F. and the average temperature difference between the gases and the heat absorbing surface is 1100 to 1150 deg. In waste heat work, the temperature of the gases entering the boiler varies widely, ranging between 950 deg. and 2000 deg. F. or higher. With a gas temperature of say 1400 deg. entering the boiler and with a working pressure of 150 lb. the average temperature difference between the gas and heating surface is approximately 480 deg. F. For this small temperature difference, in order that the absorption per sq. ft. of heating surface equal that of a coal fired boiler at rating, the rate of heat transfer will have to be about 7 B.t.u. per hr. per sq. ft. per deg. difference in temperature against 2.75 to 3 B.t.u. per hr. per sq. ft. per deg. difference for direct fired practice. In other words, the heat absorption per sq. ft. of surface in a waste heat boiler must be from 2.5 to 2.75 times as great as in direct fired boilers. Furthermore, with direct fired boilers about 65 to 70 per cent of the heat is absorbed by radiation and from 30 to 35 per cent by convection. Since no heat is absorbed by radiation in the waste heat boiler, the necessity for high velocities may be appreciated.

Gas velocities are commonly expressed in terms of the weight of the gas per sq. ft. of flow area per hr. This figure according to D. S. Jacobus for average heat transmission factors of 5 to 7 B.t.u. per sq. ft. of heating surface per deg. difference in temperature, generally runs about 3500 lb. of gas per sq. ft. of flow area per hour.

The weight of the gases can be determined from the gases produced by the materials in the primary furnace. The area of the passages can then be determined for any velocity by dividing the total weight of gas produced per hour by the required velocity.

The rate of heat transference is given by the formula

$$R = A + B\left(\frac{W}{a}\right)$$

in which

R = transfer rate in B.t.u. per hr. per deg. temperature difference, per sq. ft. of heating surface.

A and B are constants found in the table.

W = weight of gases flowing per hour.

a = area of gas passage.

The part of the above expression $\frac{W}{a}$ is known as the

mass velocity factor of the boiler. For the same mass velocity, the water-tube boiler will give a higher rate of heat transmission than the fire-tube boiler. The fire-tube boiler, however, has a lower friction loss which makes it possible to increase the mass velocity while the draft loss is kept constant. The fire-tube boiler will, therefore,

VALUES OF CONSTANTS USED IN FORMULA FOR DETERMINING RATE OF HEAT TRANSFER

Outside Diameter of Tube	Fire Tube		Water Tube	
	A	B	A	B
1	3.5	.0013		
2	2.0	.0008		
3	1.5	.00065		
4	1.1	.0005	2.0	.0014

give a higher rate of heat transfer than the water-tube with the same weight of gas.

By varying the size and length of the tubes the number of passes, etc., any desired gas velocity and hence, almost any desired rate of heat transmission may be obtained.

Power in Waste Heat

When contemplating the installation of a waste heat boiler it is desirable to estimate the probable amount

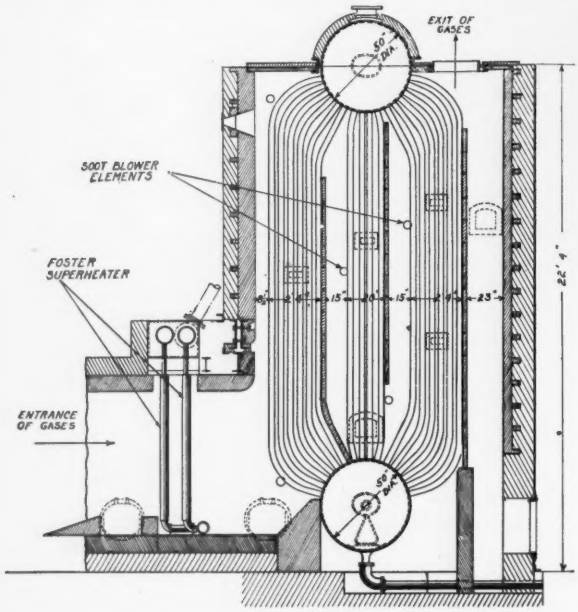


FIG. 1. WASTE HEAT BOILER OF THE VERTICAL WATER TUBE TYPE EQUIPPED WITH SUPERHEATER

of power that may be secured from the available gases. The power obtainable is dependent upon the weight and temperature of the gases and these factors vary widely in different industries. Temperatures will vary all the way from 950 to 1000 deg. in the case of oil stills to 2000 and 2200 in brick kilns.

The maximum available horsepower that may be secured from the gases may be determined by the following formula:

$$Hp. = \frac{W(T - t)s}{33{,}000}$$

Where

W = the weight of gases passing per hr.
T = temperature of gases entering heating surface.
t = temperature leaving heating surface.
s = specific heat of gases.

Draft Requirements

The high velocities considered necessary for a desirable heat transfer rate lead to a frictional resistance which makes the use of a natural draft stack impractical. Not only must the resistance to the gases through the boiler and flues be overcome but it must be remembered that on account of the low temperatures of the gases entering the stack, the effectiveness of the stack is re-

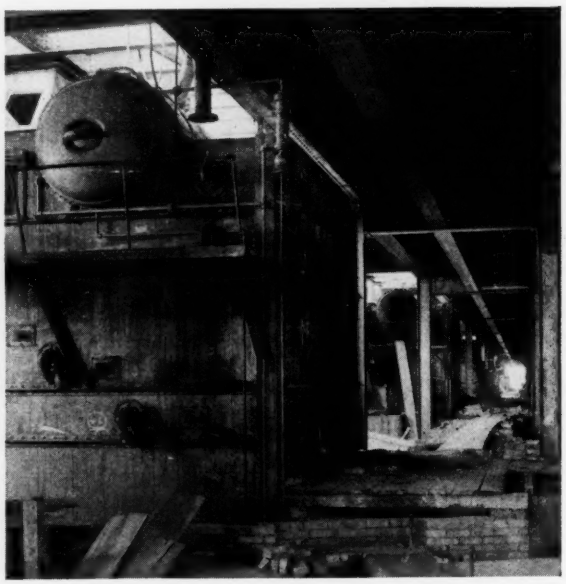


FIG. 2. SEVEN 601 HP. WASTE HEAT BOILERS OF THE TYPE SHOWN IN FIG. 1, USING GASES FROM OPEN HEARTH FURNACES

duced; consequently additional draft must be supplied to compensate for this reduction. With waste heat, the temperature of the gases entering the stack instead of being 1000 to 1200 deg. as is the case where no waste heat boilers are installed, will be 450 or 500 deg. Under such conditions a stack 160 ft. high instead of giving a draft of 1.4 to 1.6 in. at its base will give approximately 0.9 in.

A system of induced draft is, therefore, almost universally used in connection with waste heat work. Such a system not only furnishes the required draft through the boiler but in some classes of work materially improves the operation of the primary furnace. A fan for this service must be capable of handling the maximum volume of gas that the furnace may produce and of maintaining a suction equivalent to the maximum frictional resistance of such volume through the boiler plus

the maximum draft requirements at the furnace outlet. The fan must be figured on the safe side and the loss of draft in the fan connections should be considered in all cases.

The location of the fan will depend upon the number of passes in the boiler and the point of entrance of the gases. For and waste heat boiler where the gases enter at the bottom, if the number of passes is odd, the point of removal of the gases and consequently the draft producing equipment, will be at the top of the boiler. If the number of passes is even, the fan will be most conveniently located at the bottom or rear of the boiler.

Use of Economizers and Superheaters with Waste Heat

Economizers, if properly installed, can be used advantageously in connection with waste heat boilers and are frequently used in commercial practice. The economizer problem in waste heat work, however, will differ widely from the economizer problem in direct fired installations. The ratio of gas weight to water weight in a waste heat economizer installation is much higher in comparison with the direct fired boiler and if a waste heat and a direct fired boiler having the same heating surface and developing the same capacity are fitted with economizers of similar design and surface, it will be found that the economizer fitted to the waste heat boiler will increase the temperature of the feed water more than the one fitted to the direct fired boiler.

Ordinarily, economizers are designed and installed so that the temperature of the feed water leaving the economizer will be lower than that due to the pressure at which the boiler is operated under overload conditions, in order to avoid steaming. Should steam be formed in this economizer, the water would be passed into the boiler in slugs, causing undesirable operating conditions. It is, therefore, obvious that economizers regardless of their use, must be designed to supply feed water to the boiler at temperatures below steaming temperatures. Because of the foregoing reasons, economizers designed for use in connection with waste heat boilers have much less heating surface than those installed for use in direct fired practice. Due to possible irregularities in the operation of the primary furnace, an ample factor of safety should be allowed in the allowable temperature difference between the feed water temperature and the steam temperature. D. S. Jacobus and Arthur D. Pratt state that, in general, with low moderate gas temperatures the economizers must not heat the feed water to a point closer than 60 deg. F. to the steaming temperature of the boiler. The amount of economizer surface necessary to give this result, they say, will vary with the gas weight and temperature conditions, but in the average waste heat installation with entering gas temperatures of from 1000 to 1500 deg. F. it will usually be from 30 to 35 per cent of the boiler surface.

Superheaters may also be used with waste heat boilers with very favorable results. Owing to the low temperature of the exit gases in these boilers, superheaters are generally installed in the entering gas passage.

A waste heat boiler equipped with a superheater is shown in Fig. 1. Figure 2 shows seven 601 hp. waste heat boilers equipped with superheaters, being installed in a steel mill for use in connection with open hearth furnaces. Since the gases from open hearth furnaces are heavily dust laden these boilers are all provided with mechanical soot blowers for the purpose of keeping the heating surfaces clean.

Special Fuels

Gaseous Fuels, Their Source of Supply, Chemical Composition ahd Systems of Burning

OF THE FOUR FORMS in which fuel is burned, gas, liquid, powdered and lump, the first is the best because it can be most intimately mixed with the air for combustion. It is necessary, in order to secure combustion, that each molecule of combustible matter be brought in contact with the required amount of oxygen. This result is most easily accomplished with gas because each particle is free to combine with the necessary air.

Of the many gaseous fuels available, only a few are used under boilers. Of these blast furnace gas and natural gas are the most important although coke oven gas is used to some extent. Installations burning gas are confined to those localities where it is produced. Blast furnace gas is used at the smelters for generating power for use in the mill. Natural gas is used in industrial plants not too distant from the wells where its low cost makes it comparable with coal.

Blast furnace gas is a by-product formed in the process of reducing iron ore. The combustion of the coke used takes place in an atmosphere lean in oxygen and consequently quantities of CO are formed. The composition of this gas varies considerably, depending on the amount and quality of coke used per ton of ore but the following is a fairly representative average: Hydrogen, 10 per cent; nitrogen, 60 per cent; carbon monoxide, 28 per cent, and carbon dioxide, 11 per cent. The hydrogen is usually small so that the combustible is almost all CO which has a heating value of 4380 B.t.u. per lb. or at standard conditions (14.7 lb. pressure and 62 deg. F.) 322 B.t.u. per cu. ft. As this gas is 28 per cent, the B.t.u. per cu. ft. is about 93. This gas requires 0.145 cu. ft. of oxygen per cu. ft. of gas for combustion, which will be supplied in 0.69 cu. ft of air. In practice 1.0 cu. ft. is used. The heating value per cubic foot of mixture is about 50 B.t.u.

Natural gas is much richer than blast furnace gas. Its average composition is about as follows: Carbon dioxide, 2.0 per cent; carbon monoxide, 0.5 per cent; nitrogen, 1.5 per cent; oxygen, 0.5 per cent; methane, CH_4, 93.5 per cent; ethylene, C_2H_4, 0.5 per cent; hydrogen, 1.5 per cent. The largest constituent, CH_4, has a gross heating value of 23,850 B.t.u. per lb., or 1003 B.t.u. per cu. ft. and the gas as a whole has about 950 B.t.u. per cu. ft. The oxygen requirements are 1.9 cu. ft. per cu. ft. of gas, or 9.0 cu. ft. air per cu. ft. gas. The B.t.u. content per cu. ft. of theoretical mixture

is practically 100. It will be seen that for equal volume of combustible mixtures the natural gas has about twice the heating value of blast furnace gas.

Aside from the fact that gas fuel can be burned with less air requirements than any other kind of fuel, it is more easily handled. It is simply taken from the distributing mains, adjusted to the correct feed pressure and fed to the furnaces. There is no ash formed that has

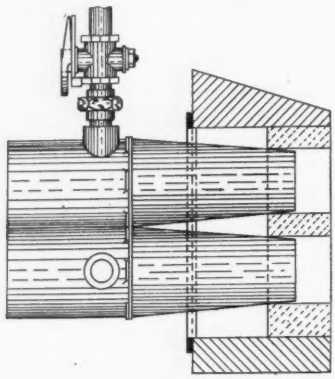


FIG. 1. GAS BURNER IN WHICH THE GAS IS FED IN TOWARD THE CENTER OF THE NOZZLE THROUGH NUMEROUS SMALL APERTURES IN THE SHELL

to be disposed of, and, as a rule, with correctly proportioned combustion spaces, the soot nuisance is less.

Gas requires a much less expensive equipment than coal. The comparative cost of gas and coal and gas and oil can be found in a chart included in the section on Fuel Oil. This table takes into consideration the different efficiencies and the calorific values met with in practice. The costs are f.o.b. plant and should include labor,

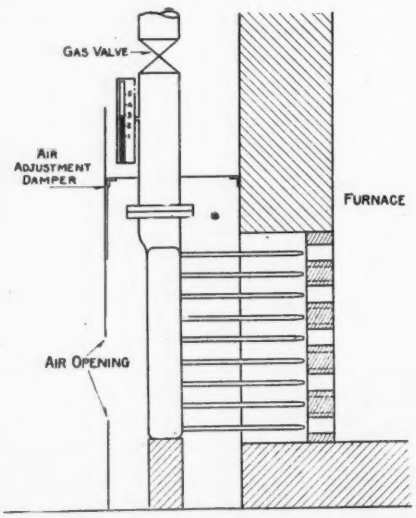


FIG. 2. A BURNER COMPOSED OF MANY SMALL NOZZLES

maintenance or depreciation. Firing conditions are easier, boiler and furnace maintenance is less and there is no labor required for handling either fuel or ash when burning gas. Gas is easily adjusted to the load so that there is no loss due to banking fires.

It is important in burning gas, as in burning any other fuel, that the combustion chamber be of the right size. Practice varies somewhat, but 0.2 cu. ft. per sq. ft. of heating surface or 2 cu. ft. per boiler horsepower is a fair average. The pressure varies with the length of gas passage in the furnace, but ordinarily should be kept around two to eight ounces. The velocity of the fuel at the nozzle should be greater than the rate of propagation of the flame, but should not be so great that unconsumed combustibles reach the first pass of the boiler. This velocity for best results should be as near the rate of propagation as possible. If, however, it is too near, pulsations in the flow will cause flarebacks. The rate of propagation of the flame in a perfect mixture of combustible and air is about 1000 ft. per sec. As the mixture is not perfect at the burner this velocity will be reduced to about 700 ft. per sec. The total area of the passage for gas and air at the burner should be about 1.6 sq. in. per boiler horsepower. No one burner should be expected to carry more than about 30 hp.; in other words, the total area of a burner should not exceed about 50 sq. in. or the diameter should not be greater than 8 in.

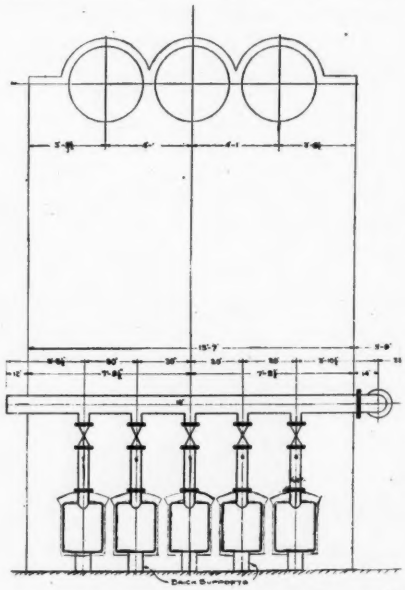


FIG. 3. AN INSTALLATION OF A BATTERY OF THE BURNERS SHOWN IN FIG. 2

The ratio of the areas of the gas and air nozzles varies with different gases as, in general, every gas requires a different quantity of air for complete combustion. For equal volumes, natural gas requires about 12 times as much air as blast furnace gas, so that the areas of the nozzles will be in this proportion.

As the excess air requirements are low, the volume of the flue gases is less than with coal, consequently the passage areas can be lessened by putting in more baffles to give a longer travel which facilitates absorption.

The burners are all built along the principles of the Bunsen burner in which the velocity of the fuel gas through a tube induces a flow of air for combustion. There are, of course, many varieties and forms of burners brought out by the various manufacturers. Figures 1 and 2 will serve to illustrate two applications for burning gas. The first burner is composed simply of two concentric casings and a nozzle. The annular space between the two casings is sealed off and constitutes the gas chamber. A great number of small brass studs are

driven through the inner case and drilled through in such a way that a jet of gas is introduced into the inner case in the direction of the nozzle so as to give a swirling motion to the combustible mixture that is obtained by the mingling of the gas with the air that is induced through the open end of the inner tube. The nozzle provides a means of obtaining better diffusion before the gas enters the furnace. The amount of air can be regulated by a kind of gate valve that can be slid across the open end of the casing.

The second burner consists of a number of long parallel slender pipes connected at their bases to a common gas chamber. The other ends of these pipes are provided with nozzles. This chamber with its pipes is suspended in front of the boiler in such a position that each nozzle projects a short distance into apertures in the brick work. The gas emerging from the nozzle induces a flow of air. These two constituents mix just beyond the nozzle and enter the furnace in a well diffused state. The smallness of the nozzles, which take care of about 2½ hp. apiece, insures this result. Figures 2 and 3 give an adequate idea of this installation.

The gas pressure at the nozzle ordinarily varies from about two to eight ounces. The capacity of the setting will vary as the square root of the pressure if the furnace capacity permits of combustion with the same efficiency at either rating, thus if the pressure is stepped up from 2 to 8 oz. pressure or quadrupled, the capacity will be doubled.

Fuel Oil

GRADED on the basis of ease with which fuels will burn, oil ranks next to gas. The completeness of combustion with theoretical air requirements depends upon the thoroughness with which the fuel and the air can be mixed. This mixture is most complete where gases are involved because here each molecule is free to come in contact with its quota of air. Solid fuels can burn only on the surface, because that is the only place where contact with air can be made. The speed with which any given quantity of fuel can be burned is, other conditions remaining the same, proportional to the ratio of the surface presented to the volume. With a gas, of course, this is a maximum, with vapors it is less, with a spray still less, and so on down. Oil is not burned, in the vapor form, to any great extent, under boilers, but is introduced in the form of a fine mist or spray by the use of several different methods. In the furnace, this mist is vaporized and gasified before it ignites. In the first experiments in burning oil, it was attempted to fire the fuel in a manner similar to that in which coal is fired. It was spread out on a shallow pan and was supposed to burn on the surface.

Difficulty was experienced in supplying sufficient air for combustion and the oil was not maintained at a temperature sufficiently high to volatilize the oil in quantities large enough to furnish the required capacity.

For successful firing, the atomization must be thorough. When atomized, the minimum amount of air requisite for complete combustion must be brought in contact with it through suitable vents in the floor of the combustion space or through the firing doors. It must be burned in the presence of a refractory material which will radiate heat to assist the combustion, and the combustion space should be large enough to permit complete combustion before the flame can be cooled by the boiler heating surfaces. The flame must be spread out to distribute the heat uniformly on the heating surface so as not to produce a blowpipe effect.

There are probably as many patents on oil burners as there are on carburetors, but there are a number of fundamental types, as shown in Fig. 1, that may be mentioned. There are two general types, the steam or air jet and the mechanical atomizer. The first form, known as the drooling burner, is probably one of the most commonly used. It is simply a casting containing two chambers and two slots. Oil in the upper chamber oozes or drools out and onto the spray of steam or air from the lower chamber, where it is broken up and carried into the furnace.

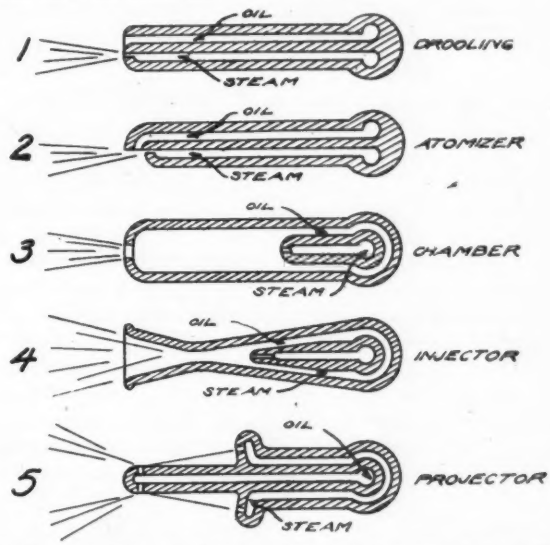


FIG. 1. FIVE FUNDAMENTAL TYPES OF OIL BURNERS USED IN STEAM GENERATING PLANTS

Number 2 is the atomizer burner. Here the oil orifice is brought farther down and turned so that the steam spray sweeps across it, brushing off the oil. This is an old system and one that is capable of producing a very fine mist. The chamber burner is shown in No. 3. In this burner, the oil and steam are more or less mixed in an inner chamber and so pass out of the nozzle; here the expansion breaks up the particle into a mist and the oil is thus carried to the combustion space. Number 4 is an injector burner, the principle of which is the same as that of any injector. The oil is sucked in by the action of the jet. The two mingle and, in the rapid expansion in the flared nozzle, the particles of oil are broken up to a minute size. The projector type, No. 5, is somewhat similar to the atomizer burner, the only difference being that the steam nozzle is located farther back from the oil orifice and the steam is partially expanded and dry when it brushes past the oil. A modification of the drooling type that has a lip under the spray nozzle to catch all the oil that is not atomized and re-expose it to the jet is used extensively in locomotive practice. Form 3, the chamber burner, or inside mixing type, is made in a number of forms which differ mainly in the shape of the exit nozzle. The form shown is the simplest. The design

of the tip is a matter of great consequence, as the physical formation of the spray is dependent on the configuration of the orifice. The spraying effect is heightened by inserting a conical core in the orifice from either the inside or outside. Giving the mixture a rotary motion before it passes the nozzle effects a better diverging action, but the twirling motion tends to separate the oil from the air or steam and it is questionable whether or not there is an advantage gained. By putting a ball in the outgoing spray, further division of the oil particles is obtained. This method is simply the old dancing ball, the superior effectiveness of which is questionable. A departure from any of these systems is one in which the

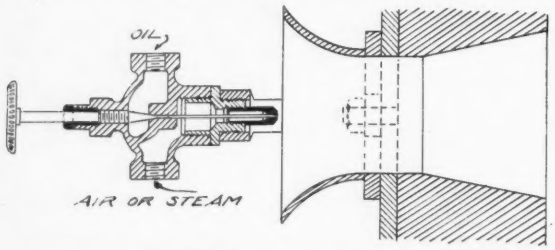


FIG. 2. HIGH PRESSURE BURNER, OUTSIDE MIXING

mixture is sprayed through a great number of small holes. This burner, on account of its multiplicity of holes, is called the pepper-box nozzle. The nozzle functions under a certain difficulty in that it is more likely to be choked up with foreign particles in the oil, and deposited carbon than the other types. Figures 2 and 3 show two types of outside burners in more or less detail, the first for high pressure and the second for low pressure air or steam. These nozzles throw a cone-shaped spray. It will be noted that in these two cases the burner is outside the furnace and that the spray enters

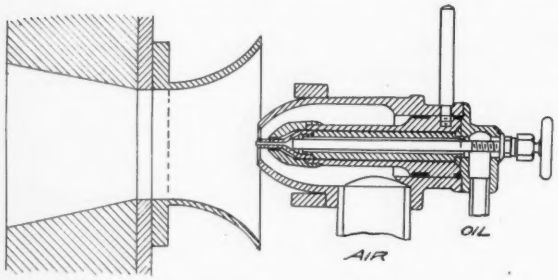


FIG. 3. LOW PRESSURE BURNER

through a venturi orifice sucking in the necessary air for combustion.

Burners are classified arbitrarily as being either high or low pressure; anything over 2 lb. is considered high and anything under is low. The difference in the burner is mainly in the size of the air or steam openings. For low pressures they should be large. There is not much choice as to whether air or steam should be used for atomization, the costs are about the same, amounting to about two per cent of the output of the boiler. This includes power for delivering the oil under pressure. It is not logical to express this item in terms of boiler output, because the question of furnace efficiency is a controlling factor. When steam is used, it should of course be dry or superheated so as to decrease the heat carried away by the moisture. Steam is used largely on locomotives and stationary plants where water is not at a premium. At sea, however, air is invariably used. On land where there are a large number of boilers, air can be used with slightly better economy.

The mechanical atomizer type of burner performs the same function as the jet burners without air or steam. The oil is atomized and fired mechanically. There are two principal methods of firing mechanically. In one system, oil under high pressure is brought to a small nozzle through guide vanes so arranged as to give the fluid a rapid swirling motion. The small orifice breaks

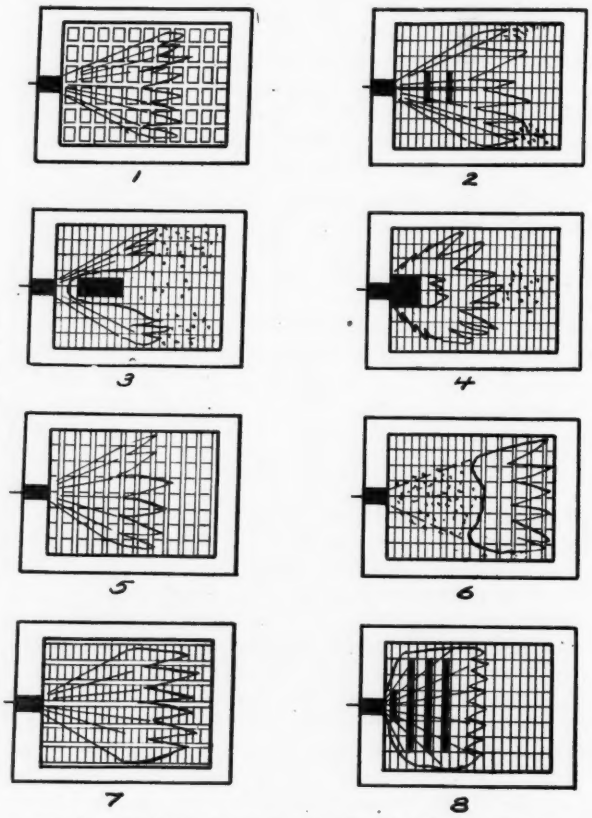


FIG. 4. ARRANGEMENTS OF AIR INTAKE PORTS FOR BEST EFFICIENCY

up the stream into fine particles and the swirling motion spreads the spray. The action is similar in many ways to the well-known garden variety of water sprinklers. The division of particles is, however, carried to a much further degree.

The other type is the centrifugal atomizer. This consists of a disk placed just above the floor of the furnace that is rotated at a high speed by a motor or turbine. Oil is allowed to flow out onto the surface of the disk through the hollow shaft. The rotation of the plate flings the oil out into the furnace in a thin sheet of fine spray. Combustion takes place in a ring around the disk. As the flame is fairly close to and entirely surrounds the burner, experience has shown that it is difficult to keep the apparatus cool. The power consumption of these burners is somewhat less than the steam or air spray variety, usually amounting to from ½ to 1 per cent of the boiler output.

In burning this fuel, the amount of air admitted for combustion and the way it is introduced are factors of prime importance. In regulating the air supply, the object is to admit just enough for complete combustion and no more. The air should be admitted, of course, where it will produce the desired effect so that the flame will burn with just as near theoretical air requirements as possible. The arrangement and location of the brick checkerwork that forms the air intake ports are of great importance. Figure 4 shows eight different arrangements for admitting air into the furnace through the floor and the effect on the flame produced by each. In the first arrangement, the whole floor is brick checkerwork and air is admitted uniformly over the entire surface. A fan-shaped flame is produced that burns completely, but the flame does not cover all the openings so that there is always a large excess of air present and the boiler cannot be operated economically. The second installation shows two large openings under the center

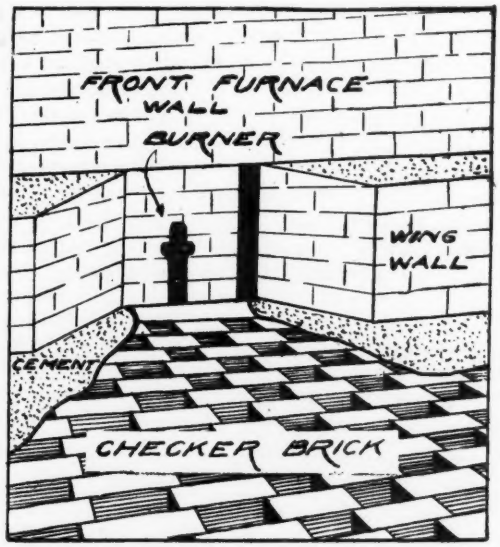


FIG. 5. A VIEW OF A COMBUSTION CHAMBER SHOWING THE FAN SHAPED ARRANGEMENT OF THE CHECKER BRICK

of the flame. This section has a plentiful air supply and will burn hottest, but the outer regions will have a deficiency and will deposit soot in the corners. In Plan 3 there is a large port close to the burner through which an excessive amount of air is taken in. The flame will tear and burn hot at the center but carbon will be deposited at the corners as in the previous case. This arrangement allows cold air to come in contact with the heating surfaces. In Plan 4, air is admitted at the burner. Intense combustion occurs in this region and the burner will consequently be overheated. Oil will escape unconsumed, heavy smoke will be evolved and carbon will be deposited. The flame will be ragged and noisy. In Plan 5, the transverse openings will always supply excess air and will not produce economy. If the openings in the front half are closed, we get the form shown in Plan 6. The fuel will not burn until it comes over the openings. It will burn clear at the tips, but will deposit carbon near the burner. The air slots in Plan 7 are longitudinal, otherwise the conditions are much the same as those that obtain with the arrangements 1 and 5. The flame will be torn more and in this respect is somewhat similar to Plan 3. Plan 8 is more nearly the correct arrangement. Air is admitted through transverse slots that follow somewhat the shape of the flame. The flame is even and burns clean at the edges. Excess air is reduced to a minimum. Figure 5 shows a fan-shaped area of checkerwork that produces an efficient flame.

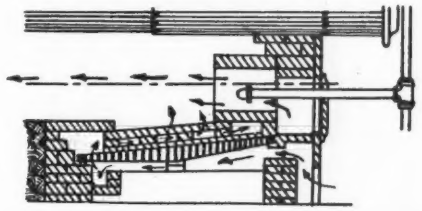


FIG. 6. CROSS SECTION OF A WELL-DESIGNED OIL FURNACE SHOWING THE PASSAGES WHERE THE COMBUSTION AIR IS PREHEATED

To obtain best results, the air for combustion should be preheated. This result can best be obtained by leading the air past incandescent brickwork in the setting before it is allowed to come in contact with the wall. Figure 6 shows an arrangement whereby this air is led in under the grate to the bridge wall and then back to the burner through a checkerwork of brick under the floor of the combustion chamber. This is only one scheme of which there are any number that accomplish the same result. Air can be taken in through isles in the side walls or bridge wall with equal effectiveness.

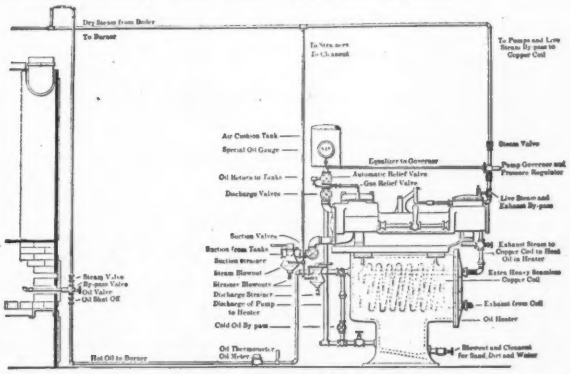


Fig. 30 Diagrammatic Arrangement of Piping for Fuel-oil System.

FIG. 7. DIAGRAMMATIC LAYOUT FOR OIL AND STEAM PIPING

Next to the burner design, the furnace proportions are the most important for efficient combustion, because no matter how perfect the atomization may be, if the furnace is of insufficient size incomplete combustion will occur and smoke will be evolved, resulting in poor economy. When oil enters the furnace in finely divided globules, it is volatilized before it begins to burn. In this operation, its volume is increased many fold and consequently its velocity is increased unless the section of the furnace is increased. If the droplets are larger, the expansion will be more and the time required for burning will be longer. The combustion space should be of such a size that fuel will have time to volatilize and burn completely to CO_2 before the gases reach the boiler heating surface.

The spray from the burners should be directed in such a way as to make use of the full volume so that no fuel

will be short-circuited to the tubes. The flame should not be allowed to impinge on the tubes. Practice has shown that approximately one cubic foot of combustion space should be provided for every boiler horsepower developed.

Another important feature is the temperature of the furnace. It should be such that the fuel can be quickly

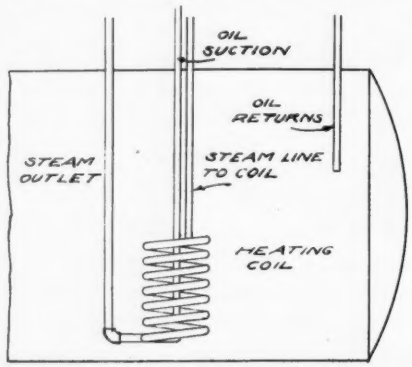


FIG. 8. ARRANGEMENT OF HEATING COIL AROUND OIL DELIVERY PIPE IN THE SUPPLY TANK

volatilized and brought up to the ignition temperature. This requires that heat be stored in the furnace lining. The inside of the furnace should be completely lined with brick composed entirely of high-grade refractory to withstand the high temperatures encountered. The brickwork should be close to the flame at or near the burner to facilitate heat absorption by the fuel.

steady, should not pulsate. One of the prime requisites of the pumping system is that it should maintain an even oil pressure at the burner. A flame that pulsates cannot be efficient all the time. It may be that the relation between air and fuel is right for one phase of the pulsation, but the rest of the time it is not. The result is that there is a gulp of excess air at one time followed by a gulp of smoke, showing insufficient air. An extra large furnace will partially compensate for this condition by allowing time for the excess fuel and excess air to mix, but it should be avoided.

All cracks in the settings should be carefully sealed to eliminate as far as possible the infiltration of cold air which has a deleterious effect on the process of combustion. This leakage has a cooling effect on the brickwork and if it is continuous tends to prolong the life of the lining, but if the composition of the brick is sufficiently good, the cooling is unnecessary and it is inefficient.

Figure 7 shows a diagrammatic layout of the oil and steam piping system. Oil is taken from the storage tank as shown in Fig. 8 through a pipe which is surrounded at its end by a steam heating coil that supplies enough heat in cold weather to put the oil in such a condition that it can be delivered to the suction of another pump in the boiler room. This pump raises the oil to feed pressure and then passes it through a heater which raises the temperature to just below the flash point, heat being supplied to this tank by the exhaust steam from the pump through a large copper coil. In case of necessity when the oil is extremely cold, live steam can be bypassed to the heater. Here the fuel is passed through

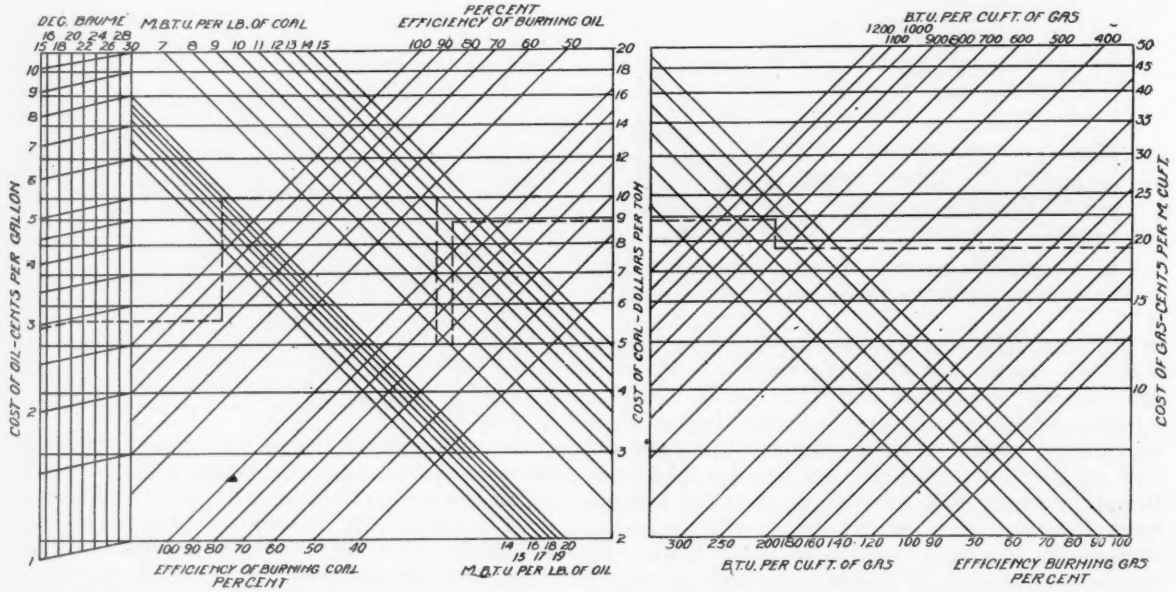

DEG. BAUME
M.B.T.U. PER LB. OF COAL
PER CENT EFFICIENCY OF BURNING OIL
COST OF OIL-CENTS PER GALLON
COST OF COAL-DOLLARS PER TON
EFFICIENCY OF BURNING COAL PERCENT
M.B.T.U PER LB. OF OIL
B.T.U. PER CU.FT. OF GAS
COST OF GAS-CENTS PER M CU.FT.
B.T.U. PER CU.FT. OF GAS
EFFICIENCY BURNING GAS PER CENT

FIG. 9. CHART FOR DETERMINING RELATIVE COSTS OF OIL, GAS AND COAL FOR EQUAL ECONOMY

Combustion arches and target walls are not to be recommended because the corrosive action is prominent at these points and the cost of maintenance will therefore be increased. The flame should be distributed evenly throughout the furnace so that there will be no localization of the heat, as this condition sets up undue strains on the setting making frequent repairs necessary. For the same reason, the flame should be

a strainer to filter out all foreign particles. In series with this heater is an air cushion tank, the same as that found on hydraulic pumps, which tends to maintain a uniform pressure. Where the pressure required is not too high, a standpipe can be substituted for the air cushion. From the heater the oil is metered and passed to the burner, steam for atomizing being taken direct from the boiler or from an adjacent boiler. A system

using compressed air would consist simply of a lead from an air compressor tank.

Care should be taken to see that all joints are tight, as oil has a peculiar penetrating quality that permits it to leak easily from carelessly made connections.

Provision should be made for blowing down the system with steam to purge it and carry off the tarry sediment that accumulates. The heater likewise should be provided with a blowoff valve to remove the water, sand and dirt which collect on the bottom.

Any oil that leaks from the pumps should be disposed of as soon as it collects because, if it is allowed to stand, an unnecessary fire hazard results. The system should be so arranged that when it is not in use all oil will drain back to the reservoir. The burner should be provided with some device that will automatically close the oil supply if for any reason the steam is cut off, in order to prevent the flooding of the furnace with unatomized oil which would be likely to result in a disastrous explosion.

The available oil supply should be sufficient to run the plant for at least two or three weeks. Best practice seems to indicate that storage tanks should be built underground with the surface of the oil at least 3 or 4 ft. beneath the surface and that the supply should be divided among several tanks. Practice must always, of course, conform with existing ordinances on the subject. The tanks must be adjacent to or under a railroad siding so that the tank cars can be unloaded with facility, and there must be a steam supply at the unloading station which can be connected with the heating coil in the car to render the oil sufficiently fluid in cold weather so that it will drain out.

In comparing relative costs of oil and coal, the fixed and operating costs and also insurance, depreciation and maintenance charges must be considered. The fixed and operating costs for oil are relatively low, as one man can readily take care of from eight to ten boilers. Standby losses are reduced to a minimum because the boiler capacity can almost instantly be adjusted to the load and banking periods are entirely eliminated. On the other hand, insurance charges are usually high due to the high fire hazard and unless the furnace design is good, the maintenance charges can be excessive. Thus in calculating comparative ultimate economies these charges should be summed up and expressed as so much per pound of fuel fired.

Figure 9 is a chart for determining how much can be paid for oil to compete successfully with coal at a certain price. Gross prices are used in both cases. Starting with the price per ton paid for coal, we go to the left to the efficiency obtainable burning coal and then up to the B.t.u. content of the coal, then left again to the B.t.u. per pound of oil, thence down to the efficiency of burning oil; then horizontally to the left to the Baumé of the oil and then diagonally down to the left to the price that can be paid for oil in cents per gallon.

The majority of coal-burning boilers operate on about 70 per cent efficiency, 75 per cent is fair practice, 77 per cent is very good and 80 per cent is exceptional; while with fuel oil, 75 per cent efficiency is quite ordinary and 80 per cent is not uncommon.

Taking a specific case, start with coal at $5 per ton, go to the left to 70 per cent coal-burning efficiency then up to 13,000 B.t.u. per lb., then over again to 18,500 B.t.u. per lb. for oil, thence down to 75 per cent oil-burning efficiency and then over to, say, 20 deg. Baumé and from there downward to the left to the price. Here we see that we can afford to pay about 2.95 cents per gallon for oil, under the conditions assumed.

Colloidal Fuel as Developed by the Submarine Defense Association of New York

DURING the war, when an adequate fuel supply for our navy and merchant marine was all important, the apprehension of an impending oil shortage moved the Submarine Defense Association of New York to investigate the possibilities of employing a combination of oil and pulverized fuel, primarily to conserve the oil supply.

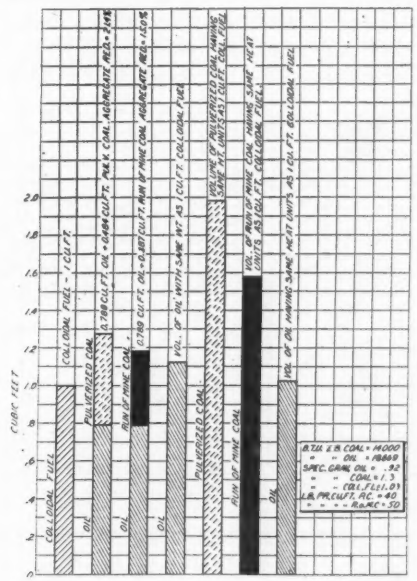

CUBIC FEET
COLLOIDAL FUEL
OIL
PULVERIZED COAL
RUN OF MINE COAL
COLLOIDAL FUEL = 1 CU. FT.
0.780 CU. FT. OIL + 0.44 CU. FT. PULV. COAL, MOISTURE FREE = 2.148
0.780 CU. FT. OIL + 0.80 CU. FT. RUN OF MINE COAL, MOISTURE FREE = 1.576
VOL. OF OIL WITH SAME WT. AS 1 CU. FT. COLLOIDAL FUEL
VOL. OF PULVERIZED COAL HAVING SAME B.T.U. UNITS AS 1 CU. FT. COLLOIDAL FUEL
VOL. OF RUN OF MINE COAL HAVING SAME HEAT UNITS AS 1 CU. FT. COLLOIDAL FUEL
VOL. OF OIL HAVING SAME HEAT UNITS AS 1 CU. FT. COLLOIDAL FUEL
B.T.U. P. LB. COAL = 14,000
" " " OIL = 18,869
SPEC. GRAV. OIL = .92
" " COAL = 1.3
COLLOIDAL FUEL = 1.01
LB. PER CU. FT. AC. = 40
" " " RANK = 50

FIG. 1. VOLUMETRIC COMPARISONS BETWEEN COAL, OIL, AND COLLOIDAL FUEL

The first step in the series of experiments that followed was an attempt to fire pulverized coal and oil simultaneously into the furnace, through separate burners. This gave rise to the idea of mixing the fuels before they entered the furnace instead of after. Lindon W. Bates, engineer of the Defense Association, working on this idea evolved after numerous experiments, a substance which is known as colloidal fuel.

Colloidal fuel is a blend of liquid hydrocarbons with pulverized carbonaceous material, combined in such a way as to produce a stable fuel adaptable to atomization for firing in a furnace. It is made in three forms so-called, liquid, gel and mobile paste. The name is not strictly accurate because much of the solid matter is not of colloidal size; there is solid as well as colloidal suspension.

One of the most important features of this new fuel is that the poorer grades of coal, lignite and peat, can be incorporated in the product and give good efficiencies,

thus making available vast fields of lower grade fuels that have been thought to be impractical for burning.

Carbonaceous material such as that mentioned is pulverized in the usual way so that 95 per cent will pass a hundred-mesh and 85 per cent a two hundred-mesh screen. The oil is mixed with a pasty substance of about the consistency of axle grease which is called a "fixateur" and then stirred into the coal. About 10 per cent of this substance is required to keep the solid particles in suspension.

Liquid fuel is composed of from zero up to 40 per cent of solid material. Above this and up to 75 per cent, solids can be incorporated in the mobile pastes.

The solid particles will remain in suspension for an extended period. Six months after a batch had been compounded, specimens taken from the top and bottom of the tank showed only about 2 per cent more coal particles in the bottom than in the top.

Using fair coal, colloidal fuel will contain more heat units per gallon than oil and will therefore require less storage space for a given heating value. Figure 1 will serve to show a comparison between the volumes occupied by various fuels for the same heating value.

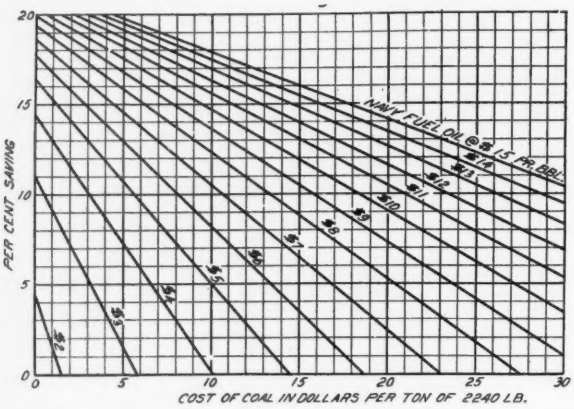


FIG. 2. COMPARATIVE SAVINGS EFFECTED WITH COLLOIDAL FUEL

The specific gravity of this fuel is greater than unity so that it can be kept under a water seal, which, besides reducing the fire risk, prevents evaporation and deterioration. This property becomes of great importance on vessels because, in case of accident and fire, what fuel leaks out into the sea will sink and quench itself and will not envelop the disabled craft in a sea of fire.

Some other points in favor of this fuel are that: An increased efficiency is obtained as compared to burning coal on a grate due principally to the fact that less excess air is used. The operation is as flexible as that with oil. Soot and smoke can be practically eliminated. Greater efficiency in the burning of the coal is realized.

As this fuel is liquid and of much the same consistency as oil, it can be pumped, piped, preheated and fed to the furnace in the same way that oil is fed. The viscosity will ordinarily vary between 160 and 350 deg. Engler, depending on the proportions of the constituent parts.

The burners for oil will serve equally well for burning colloidal fuel. No trouble has been experienced due to clogging of the nozzles.

Satisfactory results, burning this fuel, were obtained on the sea aboard the research vessel, U. S. S. Gem. On land, experiments were conducted at the Brooklyn plant of the Standard Oil Co.

As to the saving in cost effected by the use of this fuel, the association reports that at $4 per 50-gal. barrel, the saving amounts to $2 per ton. With coal at $5 and oil at $7, the saving will reach $6 per ton. Figure 2 is a chart prepared by Mr. Bates showing the per cent saving for various prices of both coal and oil on a basis of equal heat values.

Pulverized Coal

METHODS OF HANDLING, RESULTS OBTAINED, CONDITIONS JUSTIFYING USE

PULVERIZED coal has been used for many years in certain industries and its desirability has been recognized, but until recent years it has not been employed for use in steam power plants to any great extent. The rising cost of coal and the relative scarcity of the better grades and also the labor situation have given an impetus to its use in this field.

The usual method employed in handling the fuel for pulverized systems is first to crush the coal, dry it, pulverize it, store it in the powdered state, convey it to the boiler and blow it in. The installation of the apparatus necessary to perform all the operations mentioned requires a considerable outlay of capital and for this reason the system cannot be applied economically to plants of less than about 2500 hp.

There is a system for pulverizing coal that does not dry the fuel before it is pulverized and feeds it direct from the pulverizer into the furnace without storing. The installation is much less complicated and is consequently less expensive.

The fuel as admitted to the furnace is practically a heavy mechanical gas containing from 90 to 120 B.t.u. per cu. ft. Each particle of coal, having an area of about one forty-thousandth of a square inch, is completely enveloped with air and hence the conditions for burning approach those which obtain with gaseous or liquid fuels, and the fuel can be burned, in a properly designed furnace, with something approaching 100 per cent combustion efficiency. The temperature of the furnace and the quality of the ash content influence this efficiency to a great extent. If the ash fuses at a relatively low temperature, a globule of slag will form around a portion of the coal in each particle, thus preventing it from igniting. Good practice indicates that the carbon in the ash should not exceed 0.2 per cent. Excess air must be kept at a minimum to effect these results. That obtainable in practice varies from practically zero to about 30 per cent as a maximum. This variation in the air supply will produce either the reducing, neutral or oxidizing flame necessary for metallurgical work.

As both the fuel and air are supplied at a constant rate, uniform furnace temperatures result which means that the strain on the boiler and setting, due to incessant expansion and contraction, will be materially reduced, and, since the fuel and air supply are under direct control, fluctuations in the load can be met almost instantaneously by simply varying the speed of the feed-

ing device and the area of the air openings. Banking periods and standby losses are reduced to a minimum. It is unnecessary to maintain a fire under a boiler when it is not doing any work. To take a boiler off the line and hold it ready for the next peak, it is only necessary to shut off the fuel supply, the air intakes and the dampers. If an automatic non-return valve is provided in the outlet to the steam header, when the pressure drops below the pressure in the header it will close of itself, otherwise it will have to be closed by hand. The following abstracts from a log taken at the Oneida street plant during a banking period will show the results obtained.

Boiler rating ..... 468 hp.
Fuel feed shut off, uptake damper closed and auxiliary air inlets closed.....9:00 p.m
Boiler steam outlet to header closed with 175 lb. steam on boiler.....9:20 p.m.
Safety valve blown for about one minute at 15 different periods.
Steam pressure on boiler 155 lb. when fuel feed started .....7:00 a.m.
Drop in pressure in boiler during 10 hr. while fuel feed was off and during which time the safety was open 15 times for a minute each. 20 lb.
Time required to bring boiler from 155 lb. to 175 lb. and put on the line..... 4 min.

Other tests show that a cold boiler can be brought up to pressure and put on the line in from three-quarters of an hour to an hour. This practice is not

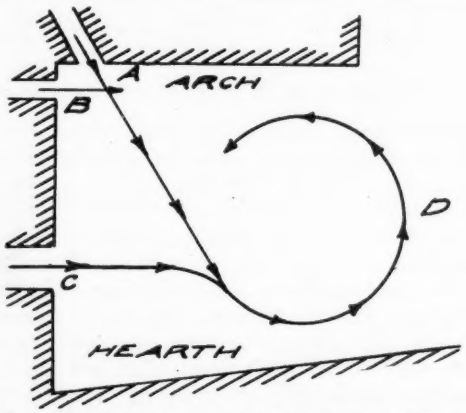


FIG. 1. ARRANGEMENT OF AIR PORTS FOR BEST RESULTS BURNING PULVERIZED COAL

to be recommended unless the demand makes it absolutely necessary because it puts a great stress on the boiler and setting that is entirely uncalled for.

Conditions governing the successful utilization of pulverized coal may be summarized as follows:

1. Fineness of pulverization.
2. Design of combustion chamber.
3. Method of feed.
4. Location and size of air intake openings.
5. Damper regulation.

The fineness of pulverization plays an important role. The smaller the particles are the more complete and the more instantaneous will be the combustion. They must be small enough to float in the stream until complete combustion has taken place. If they are too large they will settle to the bottom unburned and consequently there will be an unwarranted loss due to combustible in the ash. The size of the particles has an effect on the temperature of combustion. When it is so high that it causes an undue depreciation of the brick work, larger particles can be introduced to cool the flame. This procedure should be unnecessary, however, because the refractory should be of such a quality as to withstand any temperature normally met with.

It is necessary to know the probable maximum rate at which the boiler is to be driven before designing the furnace. Then it should be so constructed that at max-

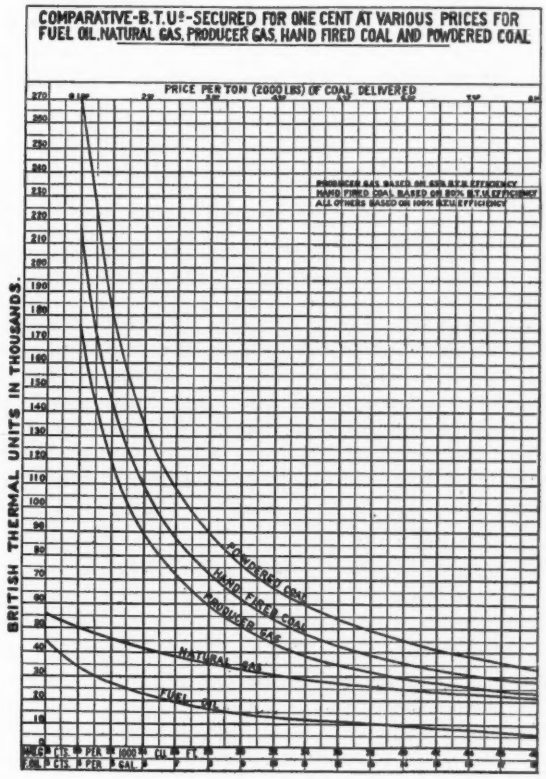

COMPARATIVE-B.T.U's-SECURED FOR ONE CENT AT VARIOUS PRICES FOR FUEL OIL, NATURAL GAS, PRODUCER GAS, HAND FIRED COAL AND POWDERED COAL
PRICE PER TON (2000 LBS) OF COAL DELIVERED
BRITISH THERMAL UNITS IN THOUSANDS.
POWDERED COAL
HAND FIRED COAL
PRODUCER GAS
NATURAL GAS
FUEL OIL

FIG. 2. GRAPH SHOWING COMPARATIVE HEAT VALUES WHEN OBTAINABLE FOR ONE CENT FOR VARIOUS FUELS

imum rating the volume will not be less than 50 cu. ft. per lb. of coal fired per minute or about 2½ cu. ft. per boiler horsepower developed. At a lower rating there will be a greater volume per horsepower and the efficiency will not be materially affected, but if this rating is increased the volume will be less per horsepower and the velocity of the gases will be greater, which will mean that they will strike the boiler heating surface only partially consumed with the result that quantities of fuel will pass up the stack without having given up their quota of heat, soot and smoke will be formed and slag will deposit on the tubes. The result of all this will be that the efficiency is lowered considerably. In order to give the fuel sufficient time to burn, the velocity through the furnace should not vary much from 6 ft. per sec.

Method of feed and direction of the flame from the nozzle are important. If the coal particles are not intimately mixed with the air for combustion, a core will

be formed and a longer time will be needed for combustion. The burner should be so placed as to direct the flame to take the most round-about way to get to the first pass. This increases the length of flame travel and therefore gives more time in which to accomplish complete combustion. Care should be taken, at the same time, to prevent the flame from scrubbing along the walls as the erosive action is very high and frequent renewals will be necessary.

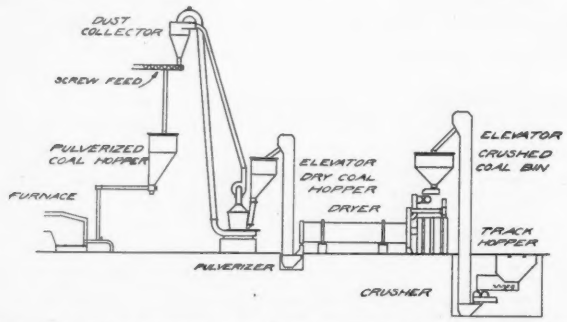


FIG. 3. ARRANGEMENT OF THE VARIOUS APPURTENANCES NECESSARY FOR A PULVERIZED COAL EQUIPMENT

Air ports should be so arranged that as the auxiliary air is drawn in it will cause a maximum turbulance and will mix thoroughly with the fuel. If the air flow is normal to the flame travel, an intimate mixture will be obtained. Figure 1 shows diagrammatically the direction of the currents. The swirling rich fuel mixture comes in at B and is met immediately by a current of hot air from A. At C more air is admitted. The result is the curve D.

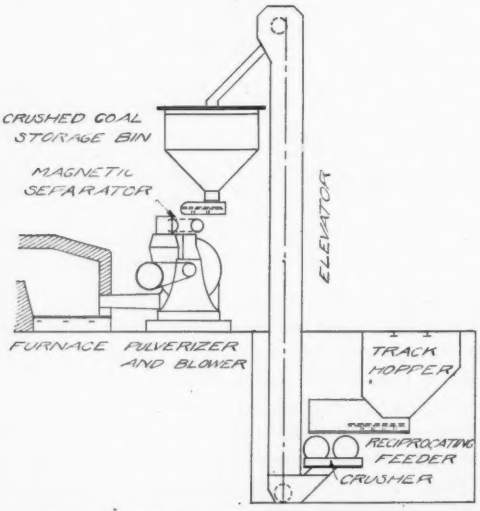


FIG. 4. ARRANGEMENT OF THE APPARATUSES OF A SYSTEM USING NO DRYER

Air entering with the fuel should have the velocity maintained as low as possible. A one-half ounce pressure at the burner should be sufficient. The flame should begin a few inches from the burner to give sufficient time for complete combustion. With a relatively high velocity the fuel will not begin to burn at a distance of from 4 to 6 ft. from the burner. Under these conditions we cannot hope for high combustion efficiency.

Damper regulation must be watched carefully while burning pulverized coal as this fuel is exceedingly sensitive to slight variations in air supply.

For installations in which a large part of the air for combustion is blown in, the draft should be practically balanced in the combustion chamber with only a slight vacuum in the first pass. The draft at the damper should be about 0.1 to 0.15 in., depending, of course, on the baffling and the resistance through the setting. A stack from 30 to 35 ft. high should be sufficient to supply this difference in pressure. When the great proportion of the air for combustion is taken into the furnace by induction, the draft requirements will naturally be greater. In a pulverized coal furnace there is no pressure drop through the fuel, so that the requirements are much less than when coal is burned on a grate.

Conditions justifying the use of pulverized fuel are, according to John E. Mulfeld, briefly as follows:

The necessity of greater output from existing equipment.

An available supply of cheap low grade fuel.

Highly fluctuating load, short peaks with long standby periods.

Advisability of eliminating as far as possible the human element.

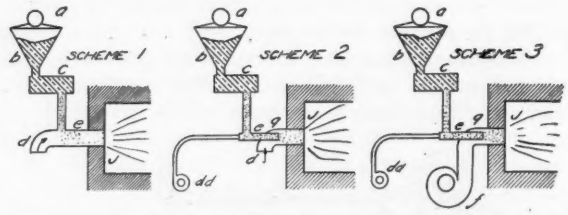


FIG. 5. THREE METHODS OF FIRING PULVERIZED COAL

One of the most far-reaching results of the utilization of pulverized coal is that fuels that have hitherto been thought unavailable or unsuited for burning can now be burned with good efficiencies. Coals containing as high as 52 per cent ash have been used with success. An efficiency of 80 per cent is easily maintained with a pulverized coal system with only a slight falling off for lower grades of fuel. The regular domestic sizes and quality of anthracite, bituminous and semi-bituminous coals as well as anthracite culm, dust and slush, bituminous and lignite slack, screening and dust are all suitable for burning in the pulverized form.

The quality of the ash is an important item to be considered in deciding on a fuel to be burned in the powdered form. A low fusing ash should be avoided because it will slag and plaster the walls of the combustion chamber and the tubes with a hard deposit that is difficult to remove.

The following relative costs for different sized installations is due to Robert June:

Considering the investment for an installation as amounting to $12.80 per kw. or 5000-kw. or 100-ton plant, and $4.80 per kw. for a 50,000-kw. or 1000-ton plant, the interest charges for the first will be 10½ cents per ton and for the 1000-ton plant 4 cents per ton.

Assuming the life of the plant to be 15 to 20 yr., the depreciation will be for the 5000-kw. plant, 12 cents per ton and for the other 4 cents per ton.

Insurance and taxes at 2 per cent will amount to

3⅓ cents per ton for the smaller plant and 1½ cents for the larger.

Repairs and maintenance have been fixed by experience at from 10 to 20 cents per ton with 10 cents a ton the absolute minimum.

The power for crushing, drying, pulverizing and transporting from track to furnace is from 15 to 20 kw. hr. per ton which at ¾ cents per kw.-hr. gives 13 cents per ton.

For a 100-ton plant 40 man hours per day at 50 cents per hour gives 20 cents per ton for labor while 120 man hours for the larger installation will amount to 6 cents per ton.

Coal for drying amounting to 1¼ per cent of the coal dried, at $4.25 per ton will cost 5 cents per ton.

Summing these quantities we get the total cost for firing for the 100-ton plant 78⅝ cents per ton and for the larger plant 43½ cents per ton.

Figure 2 is a graph showing the comparative B.t.u. secured for one cent for various prices of fuel oil, natural gas, producer gas, hand fired coal and pulverized coal.*

To use this chart first secure the price of the fuel as delivered and add to this the cost of handling and preparation, distribution and burning as well as 14 per cent on the investment for obsolescence then find the new price at the top of the graph for coal and at the bottom for oil or gas and then read up or down until the price line intersects the curve of the particular fuel under consideration and then follow to the left to the B.t.u. in 1000 units available for one cent.

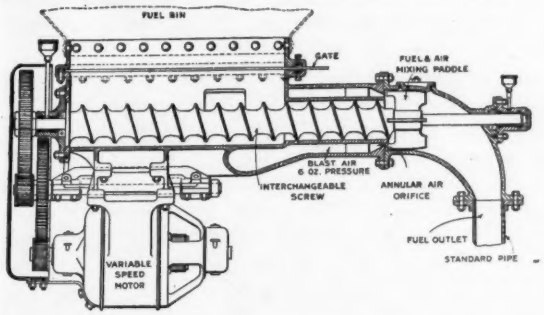


FIG. 6. DETAIL SECTION OF A PULVERIZED COAL FEEDER AND MIXER

To outline briefly the various steps in the preparation of the coal for firing as carried out by one system:

Coal is received in the cars, is dumped into a track hopper from which it is carried by an elevator to the hopper for the crusher rolls. From the crusher it passes to an indirect fired rotary dryer kiln which reduces the moisture content to about 1.0 per cent. From here the coal passes over a magnetic separator that takes out all iron scraps, nuts, bolts, etc., that would play havoc with the pulverizer. The fuel is then elevated to an overhead storage bin from which it is fed to the pulverizing mill which reduces it to the required fineness. The powdered coal is then elevated again to a distributing system that carries it to the pulverized coal bins. A variable speed feed screw takes the fuel from this bin and feeds it at the desired rate to the burning pipe through which a current of air is maintained by a blower, the quantity of which is controlled either by varying the blower speed or by a blast gate. The fuel is agitated as it enters this draft so as to procure a thorough mixture. This mixture is then fed directly into the furnace where additional air openings are provided to supply the required amount of air for combustion. These steps are shown diagrammatically in Fig. 3.

Another system dispenses with the dryer as being unnecessary, crushes and pulverizes the coal as received and fires it directly to the furnace without storing it. The quantity of the feed is regulated by the speed of the mills and the integral fan. This system is illustrated in Fig. 4.

Several general types of burners are illustrated in Fig. 5. In the first scheme the stack furnishes all the draft. Fuel is sprinkled into this current by a regulated feeding device, as it enters the furnace. The rate of firing is controlled by the uptake damper and is not as sensitive as the others mentioned. In scheme 2 the powdered coal is fed into a forced blast that constitutes only a small proportion of the air required for combustion. The remaining air is drawn in by the inductive action of the blast and by the stack draft. Accurate control of both fuel and air is maintained by regulation of the blast fan and air intake openings. In scheme 3 a forced draft is substituted for natural draft, otherwise the conditions are the same: *a* is screw conveyor for the pulverized coal, *b*, the hopper, *c*, feeding device, *d*, induced draft combustion air, *e*, primary mixing chamber, *f*, secondary air blower, *g*, secondary mixing chamber, *h*, hearth, *i*, burner nozzle.

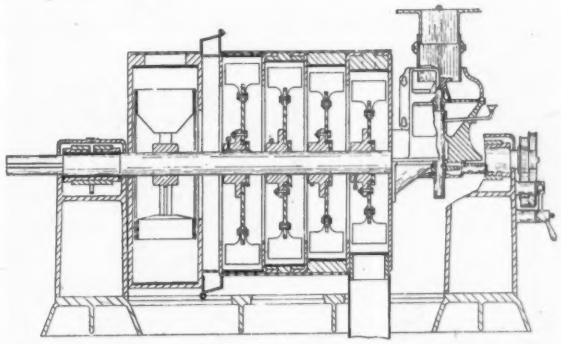


FIG. 7. A COAL PULVERIZER AND BLOWER

Figure 6 shows in detail the construction of a popular feeder and mixer. A variable speed screw feeds the fuel to a mixing paddle just in front of an annular orifice that supplies air to carry it to the secondary chamber. The screw should be of sufficient length to prevent the pulverized coal running ahead and flooding the system. The fuel in this form has properties similar to a liquid in that it seeks its level so that enough resistance must be introduced to hold back the flow.

Figure 7 shows a section of a combined pulverizer and blower. Crushed coal is fed in at the right and is pulverized in four stages by the four sets of paddles shown. The fuel then enters the fan chamber at the left and is blown directly to the furnace.

Figure 8 is a section of a plant equipped for burn-

*Compiled by the Quigley Furnace Specialty Co., Inc.

ing pulverized coal. The dryers and crushers are not shown.

Figure 9 shows a unit system that does not use the dryer. Attention is called to the cooling water circulation in the furnace walls to reduce the temperature of the brick work.

In large plants using a centralized pulverizing plant the transportation of the powder presents quite a problem. The screw feed is useful for short distances but as the length becomes excessive the tortional strains are greatly increased and the upkeep begins to amount to a considerable figure. The system of air

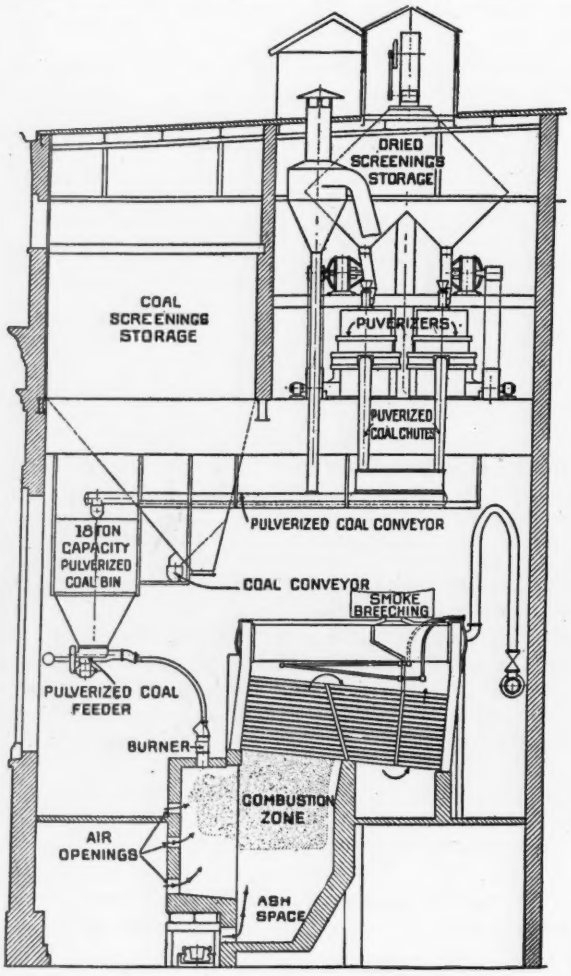


FIG. 8. SECTION OF A PLANT EQUIPPED FOR BURNING PULVERIZED COAL

flotation has been used with success; but unless the air velocity is high, the powder will settle out; this system is extravagant of air. At the point of delivery, a dust collector has to be used that will handle a large quantity of air. There is a system being used that takes advantage of the fluid quality of the powder. The fuel is forced through a small diameter pipe with alternate pistons of pulverized coal and high pressure air from a blower tank. It is claimed that this method materially decreases the amount of power required.

The question of ash disposal is one that has received a large share of attention in connection with the burning of coal in the pulverized form. The ash is necessarily in a finely divided state, a large portion of it is so small that it cannot be seen without a microscope. Particles of this size are easily carried along in the slightest breath of air and consequently are carried away with the flue gases. Of the ash that remains after the combustion of the coal approximately one-third is collected on the floor of the combustion chamber, one-third between the second and third passes and one- third leaves the setting. Some of this last third adheres to the walls of the breaching and the stack but most of it escapes unless means are provided for collecting it. Several methods have been tried for effecting this result, among

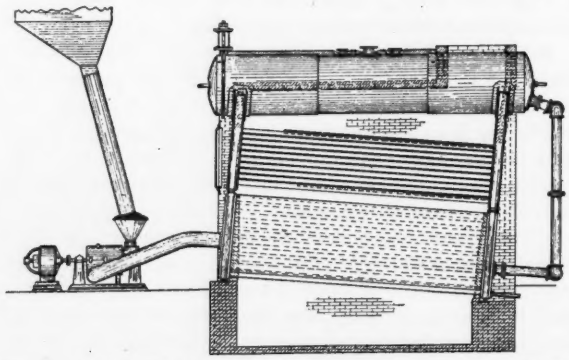


FIG. 9. COAL PREPARATION EQUIPMENT AND BOILER SETTING FOR A SYSTEM USING NO DRYER

them, electrical precipitation, moisture precipitation, dust collectors and others. Of these the mechanical dust collector is probably the cheapest and on a par with the others for effectiveness. None of them can result in perfectly dust free flue gas. It is supposed that the dust that escapes is so fine and is carried so high that its subsequent precipitation is over so large an area as not to be noticeable. One theory is that it is not precipitated except by moisture in rain. At any rate complaints from the cause have been few, fewer by far than might at first be expected. Whether or not the dust will be noticeable where there is a large group of plants burning pulverized fuel remains to be seen.

The Utilization of Pulverized Peat

By C. F. Herington

DURING these days of high fuel costs, peat is receiving some attention as a possible substitute for coal for use under boilers. Peat has been used to a great extent in European countries before now, but on account of the wide distribution of our coal fields, we have not in the past taken it up as a fuel to any great extent. We have now come to realize its value, and have devised means of burning it successfully. The most recent work along this line has been to employ it in a pulverized form.

At the present time, there is a company in the city of Minneapolis, Minn., which is successfully burning pulverized peat under a return tubular boiler, located in an office building, and is successfully carrying the load which was formerly handled with two hand-fired return tubular boilers.

The Bureau of Mines, University of Minnesota, estimates that there is, in the State of Minnesota, seven billion tons of peat, the greatest proportion of which is available for fuel; therefore Minnesota's fuel problem, which is becoming more acute each year, is being solved to a certain extent, as this company plans to have at least 10 peat machines in operation next spring.

The peat is excavated by a machine, which digs, macerates, spreads and cuts the peat into briquets at one operation. This machine requires only one man to operate it, and has a capacity of 100 tons of air-dried peat per day. After the peat is spread, the crop is allowed to lie for about two weeks, exposed to the wind and sun, when it is piled into windrows by the use of an ordinary road scraper for further air drying, and is finally put into stock piles to await transportation to the pulverizing plant.

The dry pulverized peat contains about 3 per cent moisture, 10 per cent ash, 0.82 per cent sulphur and from 9000 to 10,000 B.t.u. per lb.

The experimental work of burning pulverized peat, as conducted in this office building has brought satisfactory results. The actual comparison obtained by a weighed water test showed that about 10 per cent more peat was required to carry the same load than pulverized coal.

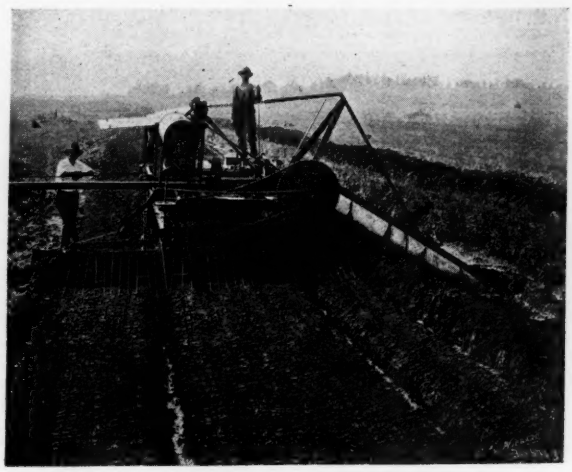


FIG. 1. REAR VIEW OF THE PEAT MACHINE

Pulverized peat burns with a longer flame than pulverized coal, due to the high volatile content. A cubic foot of pulverized coal weighs 36 lb., while a cubic foot of pulverized peat weighs 31 lb. On account of the nature of the fuel, its high oxygen content, the quantity of air for combustion can be greatly reduced over that required for coal. A slight variation in the air supply will affect the furnace conditions with peat burning more than the same variation where coal is used. The ash is very light and does not stick to the tubes. In fact, due to the high percentage of lime and low percentage of silica and alumina, it is impossible to fuse or slag the ash at ordinary furnace temperatures.

This company is now erecting a pulverizing fuel plant in Minneapolis to supply pulverized peat for small boiler plants, by delivering in air-tight cylindrical tank wagons, and expects eventually to have a network of plants in the State of Minnesota.

The following gives a brief outline of the installation and method used for obtaining pulverized fuel. The fuel is dumped from the car into a reinforced concrete hopper, from which it is fed into a roll crusher by feeders, which are operated by variable speed motors, so as to regulate the amount of peat being crushed with the number of pulverizers being operated. From this point it is carried by a belt under a magnetic separator which removes any iron or steel that has become mixed with the fuel. This belt discharges into an elevator which in turn discharges to a screw conveyor and this to a crushed fuel bin. From this bin the fuel is carried by a belt to the dryers, which have a capacity of 10 t. an hour when using fuel of a high moisture content. The dryer is of the indirect-fired type to eliminate any danger of setting the fuel on fire, firing being done by pulverized fuel. From the dryer the fuel goes to the pulverizers which have a capacity of 5 t. per hour, to a fineness of 95 per cent through a 100-mesh screen, and 85 per cent through a 200-mesh screen. Connected with the pulverizers are vacuum air separators. An air current carried the fuel to a series of collectors connected with a 50-t. pulverized fuel bin, so located that a 5-t. tank truck can drive underneath and be loaded with fuel by gravity. The truck will be equipped with a compressed air tank to facilitate the unloading of the fuel into the consumers' fuel storage tanks.

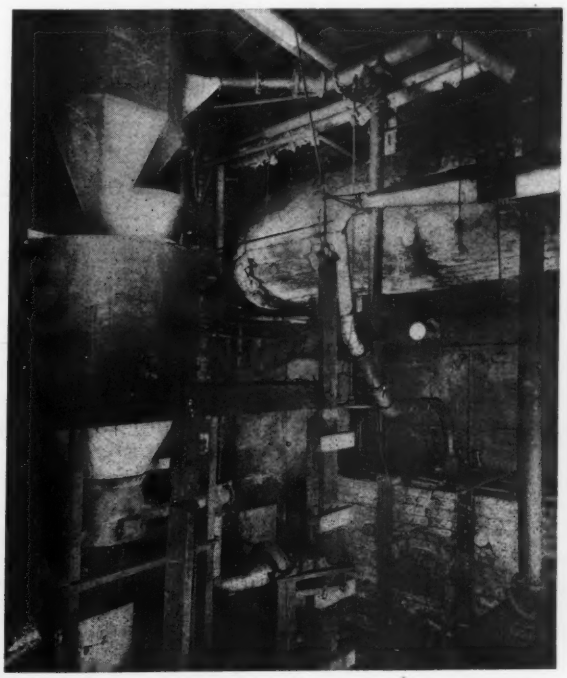


FIG. 2. AN APPLICATION OF THE RETURN LINE DISTRIBUTING SYSTEM TO A 100-HP. RETURN-TUBULAR BOILER FOR BURNING PULVERIZED PEAT

The burning equipment for the individual boiler rooms will be some form of return line system. This consists of the pulverized fuel storage bin, which is placed, where convenient, in the regular coal bins and

directly under the manhole to alley, or sidewalk, thus facilitating the discharge from tank wagon. It will be made of sufficient capacity to serve the boilers for 36 hr., at maximum load requirements. The pulverized fuel is taken from the bin by a screw conveyor, driven by a variable speed motor, through an iron pipe cross into the suction side of a high-pressure blower. From this it is blown into the main header and distributed to the different boilers through branch pipes, the same as gas or oil is taken from a header. This header continues as a return line to the collector located on top of the pulverized fuel bin, returning any fuel not used at the boilers, where it is freed from the circulating air and falls into the storage bin to be used over again.

After the fuel is eliminated, the air from the return line is returned to the suction side of the distributing blower. The excess air needed for combustion is furnished by a second pressure blower at a maximum pressure of 3 oz. This air is mixed with the fuel and air from the primary blower through a "Y" connection, located from 4 to 6 ft. from point of entrance to the boiler. The fire is controlled by the speed of the screw conveyor and a butterfly valve and baffle placed in the branch lines.

There are several distinct advantages of this system over the old system of using screw conveyors and hoppers for each unit:

The maintenance charges incidental to the old screw conveyors are eliminated. Any number of units may be served, as several booster blowers can be used and the system carried on indefinitely. Air distribution entirely eliminates the use of special hoppers and stoking equipment for each boiler. The fuel is kept in continuous circulation, thus tending to prevent its caking and bridging over in the bin with the ultimate flushing in the screw conveyor when this breaks down. When using peat as the fuel, no secondary air is required, thus further reducing the low cost of power required to furnish the fuel to the units.

In the United States, 85 per cent of the power and heating plants run not over 1000 hp. and the expense of a complete pulverizing plant has been prohibitive. This problem is solved by the centralized pulverizing plant, delivering the pulverized fuel to the consumer in tank wagons. This is not an experiment, as there is a company in Seattle, Wash., which has built up a commercial business, particularly in connection with the use of pulverized coal for boiler plants and for power and heating purposes.

Burning Pitch Under Boilers

PITCH is the residue left from the distillation of coal tar which is produced in the by-product coke oven. In the past, this residue has about supplied the demands for roofing, waterproofing and paving materials; but as the output of coke ovens has increased, there has been a surplus created. This surplus is now supplying fuel for burning under boilers.

Pitch is a blend of hydrocarbons, finely divided carbon, oxygen and some nitrogen and sulphur. Its calorific value is intermediate between coal and oil and ranges around 15,000 to 16,000 B.t.u. per lb. The point at which it becomes liquid is anywhere between 100 and 350 deg. F. depending on its composition. A proximate analysis shows its composition to be: Volatile hydrocarbons, 67 per cent; fixed carbon, 32 per cent; ash, 0.5 per cent, and moisture about 0.05 per cent.

Difficulty has been experienced, however, in burning this fuel. The volatile hydrocarbons are distilled off in great quantities at about 750 deg., making it almost impossible to introduce enough air into the furnace to support combustion when it is needed. As these volatiles are given off at a comparatively low temperature, they have to be further heated before they reach the ignition point, which takes time and, if the time allowed is not sufficient, they reach the tubes before combustion has taken place, hence huge volumes of dense black smoke are emitted. It will be seen that it is necessary in burning this fuel to provide an extra large combustion space and a long gas travel in the furnace before the tubes are reached. Even with these provisions, the combustion is likely to be incomplete because it is extremely

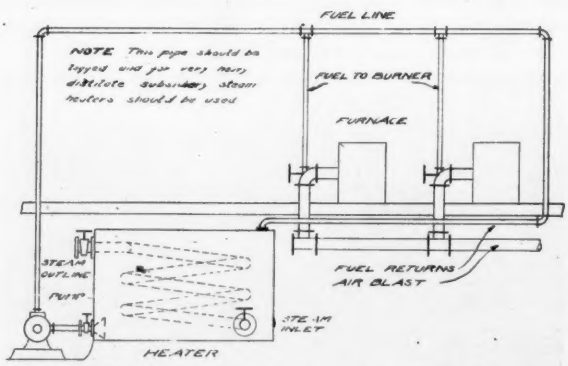


DIAGRAM SHOWING PIPING LAYOUT FOR A BOILER INSTALLATION BURNING A PITCH AND CREOSOTE MIXTURE

difficult to secure adequate mixture of air and gas. Numerous tile baffles inserted in the path of the flame have served to facilitate mixing.

Attempts have been made, but without success, to burn this fuel in conjunction with coal, on a grate. The pitch melts, giving off great volumes of gas, and spreads over the fire, forming a draft-proof blanket, thus shutting off all air when it is most needed.

Better results have been obtained by mixing the pitch with tar oils and also with creasote oils. This mixture is more fluid and when properly preheated, can be fed into the furnace like fuel oil. Pressure jet burners feeding fuel at 290 deg. F. and 75 lb. pressure are used in this connection as being more successful than either the steam or air jet atomizers.

Efficiency of 80 per cent has been obtained with this kind of installation. There are certain bodies in the pitch that hinder its being fired with a nozzle in that they clog up the openings, hence special care has to be taken in straining the fuel.

Ash Disposal Systems

THE QUESTION OF THE EFFICIENT DISPOSITION OF REFUSE PRESENTS A DIFFICULT PROBLEM IN ANY EXCEPT OIL AND GAS BURNING PLANTS

IN ANY plant burning coal, wood or any kind of industrial refuse, the question of the disposal of the ashes is always one that requires careful investigation. Plants using pulverized coal have this problem to a less degree while oil and gas burning installations present no difficulties whatever in this line.

The nature of the ash handled varies from the finely powdered, flocculent dust that usually results from the combustion of pulverized coal to the large clinkers formed by burning poor, dirty coals at excessive temperatures.

There are four general methods employed in the handling of ash: manual, mechanical, current, gravity, and any combination of these.

MANUAL HANDLING

THE FIRST is, of course, the oldest. It is used today only in small installations where the volume of refuse produced does not warrant the use of more modern methods, and to supplement any of the other systems when and wherever occasion demands.

Ash cans are used in some small plants where the amount of refuse is not large, less than a wagon load per day, in preference to barrows usually when the ash has

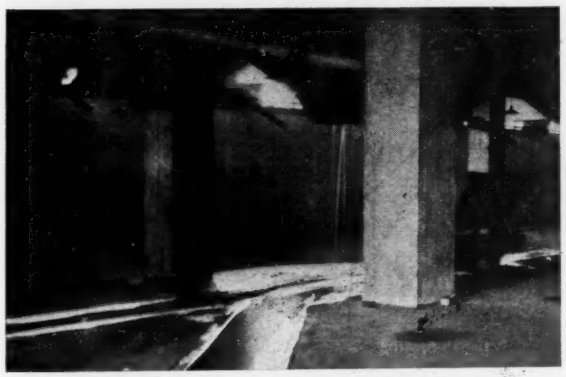


FIG. 1. INDUSTRIAL CAR ON TRACKS INSTALLED IN THE BASEMENT UNDER THE ASH HOPPERS

to be moved through a section of the plant where spillage would be especially objectionable. There should always be enough cans available to take care of a wagon load at a time so as to make it unnecessary for the wagon to wait while cans are being carried forth and back and are being filled. Where hand trucks, overhead trolleys with differential hoists, or sidewalk lifts or hoists are provided, labor charges are high, as with the wheelbarrow system.

Industrial cars are used even in large plants, with and without tracks. In places where no ash hoppers are provided under the grates, the ashes are raked out in front of the boiler and shoveled into the car. When hoppers are installed, the cars can be run under and loaded simply by opening the discharge door of the pit, thus making it possible to handle large clinkers without breaking them up. Where the ashes are raked out in front of the boiler, they give a slovenly appearance to the boiler room, and the coal piles, where hand firing is used, must be located farther back, necessitating extra labor and more lost time in firing. The cost of this installation is more than the can system and the labor charges are reduced but slightly.

MECHANICAL HANDLING

UNDER mechanical handling can be considered, chain and flight conveyors; carrying conveyors, such as apron, pan, belt, pivoted bucket; screw conveyors; monorail systems; skip hoists; cable and trolley cars; and clam shell buckets on trolleys.

FIG. 2. SECTION OF AN APRON CONVEYOR

Any kind of drag conveyor or the screw conveyor is not well adapted to handling ashes, as the high abrasive action causes excessive wear on the parts and consequent frequent renewals, making the cost of maintenance unreasonable. As the name implies, the material is simply dragged along in a trough by paddles or slabs suspended from a traveling chain. This same scraping action is present in the screw conveyor. Both the trough and the screw are subjected to wear, and the bearings in this apparatus are especially open to this abrasion. The result is that these systems are little used for this work. Their field is confined chiefly to the transportation of coal in the power plant. Coal has a lubricating action which tends to keep the apparatus in condition.

The capacity of the flight conveyor is largely dependent on the size; the speed is more or less fixed for best economy at about 100 ft. per min. An approximate rule states that for this speed, with flights one foot apart, the capacity in tons is equal to the area of the flight in square inches. Any inclination of the system will, of course, detract from the capacity figured in this way.

These conveyors are made with both the sliding shoe and roller supports. Whereas the roller type costs more initially, its lower operating and maintenance charges offset this item in a short time.

The power requirements for flight conveyors can be approximated from equation No. 1 in the section on flight conveyors for handling coal, and the screw conveyor requirements are as expressed by equation 4 in this article, using $f = 1$.

Considering the carrying systems, Fig. 2, the apron conveyor consists of wooden or steel slats attached between parallel chains to form a continuous apron or platform. The slats are placed as close together as is possible in the wooden structure and the steel slats are

usually laid overlapping to prevent material carried from falling through. The chains used to carry these plates are suspended from rollers which travel along a track. In developing these conveyors, the steel slats were first dished and then gradually deepened to form pans and buckets in order to increase the capacity of the system. A combination of the flight and rigid bucket and chain types is capable of handling material in both vertical and horizontal directions. Here buckets are fixed rigidly to the chains with the axis of the bucket parallel to that of the chain. On the horizontal run, the buckets travel in a trough and convey the material by pushing it along just as in the flight conveyor. On the vertical, the buckets assume an upright position and

FIG. 3. BUCKET AND CHAIN ELEVATOR LOADING ASH DIRECTLY INTO A RAILROAD CAR

each carries its load. These systems operate at a certain disadvantage in that they are incapable of discharging except at the end of the run.

Pivoted bucket conveyors constitute another development. In this system, the buckets are supported on trunnions at the points of articulation in the chain or at the end of extensions of the links. As these buckets are free to turn, a load can be carried in any direction. Overlapping lips are provided to prevent spillage at the loading point on a horizontal run. The trunnions of these carriers are subject to considerable wear which will occasion a considerable amount of play throughout the length of the system. Means must be provided, therefore, to take up this play at one of the sprockets, and it may even be necessary at times to take out a link.

The power requirements for V-buckets and pivoted buckets are as expressed by the equation 2 in the paragraph on this subject.

Here again the capacity is dependent almost entirely on the size of the buckets as the speed is set for economical operation. The cost of installation of this system is rather high in comparison with the scraper or apron types, but the operating costs are less and it is practically automatic. The buckets run along the basement floor under the ash hopper from which it is filled. The load is carried along to the end of the boiler room and up. On the upper horizontal run it dumps into an ash bin which is adjacent to the last coal hopper. The top of this bin is usually inclosed to prevent the dust from getting into the boiler room. From this bin the ashes are fed by gravity into a truck or railroad car for disposal.

This system is in common use in plants ranging from the medium small to the largest central stations. In large plants where conditions warrant, the system is installed in duplicate to insure against accidental stoppage due to breakage or mishaps of any kind.

These systems are frequently used for the handling of both coal and ashes in the same unit. While this practice reduces the cost of installation, it is not always to be recommended because there are times, during periods of heavy load, when it becomes necessary to handle both coal and ashes at the same time which, of course, cannot be done. There is, too, the possibility of dumping the ashes in the coal hopper or the coal in the ash hopper.

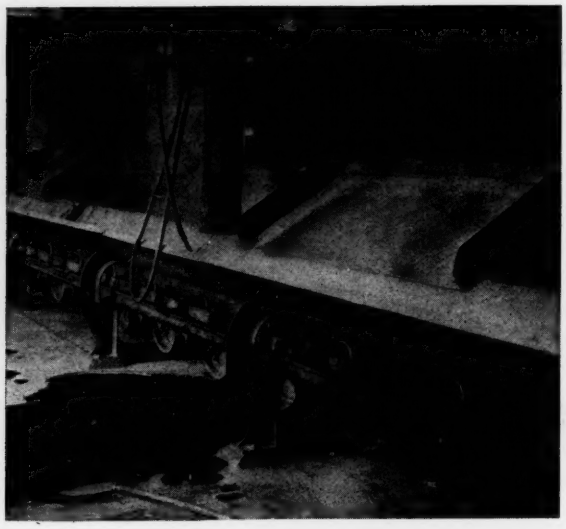


FIG. 4. PIVOTED BUCKET CONVEYOR READY TO BE LOADED FROM THE ASHPIT DOOR

Belt conveyors are little used for the disposal of ash. The material of which the belt is made has not been found suitable to handle the hot or the wet ashes. This and the abrasive action necessitate frequent costly replacements.

Where the ash has to be carried a considerable distance from the power house, and where large clinkers are produced, monorail cars can be employed with success. A dumping bucket of from 500 lb. to 3 t. capacity is suspended by a chain or wire rope hoist from the carrier. These systems include the hand hoist and hand propelled installations in the smaller plants, those that are electrically operated and controlled from the ground and those that are controlled from a cab on the carrier as shown in Fig. 5.

The bucket is lowered to the floor in front of the boiler and filled by hand; it is then carried outside and dumped into an ash bin or directly into a car. The bucket should be of such a size that it will accommodate a day's accumulation of one grate at a time. Where grab buckets are substituted for the ordinary can, a great deal of labor can be saved in the operation. Where hoppers, in connection with automatic stokers, are used this same system can handle the coal.

This system is economically applicable in various degrees of refinement to almost any plant. The cost of installation for the more elaborate varieties runs fairly high, but the exceptionally low cost of maintenance usually makes it a paying investment.

The power requirements are low and usually close to theoretical, both for lifting and rolling.

Where the ashes have to be elevated to a considerable height, skip hoists have proved successful in connection with apron conveyors, and industrial dumping cars. The

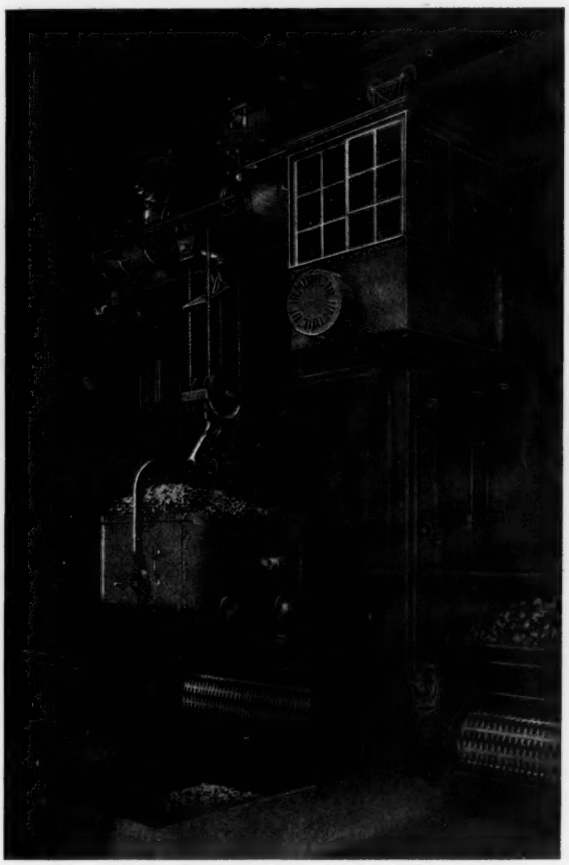


FIG. 5. OVERHEAD, ELECTRICALLY OPERATED TROLLEY CONVEYOR WITH DUMPING BUCKET. HAND LOADING IS NECESSARY

hoist is mounted usually on a steep incline and cars usually in pairs are so arranged that while one car is going up the other is coming down, thus balancing the load. The car is filled at the bottom by hand, from a hopper or directly from a horizontal conveyor. At the top it dumps automatically and returns. The operation is simple and the power requirements are small.

Current Systems

A CURRENT SYSTEM of ash handling is one in which the material is carried along by the flow of a fluid. There are three varieties of this system, the hydraulic, vacuum and steam jet.

The hydraulic or sluice systems are used only under special conditions where water is supplied plentifully

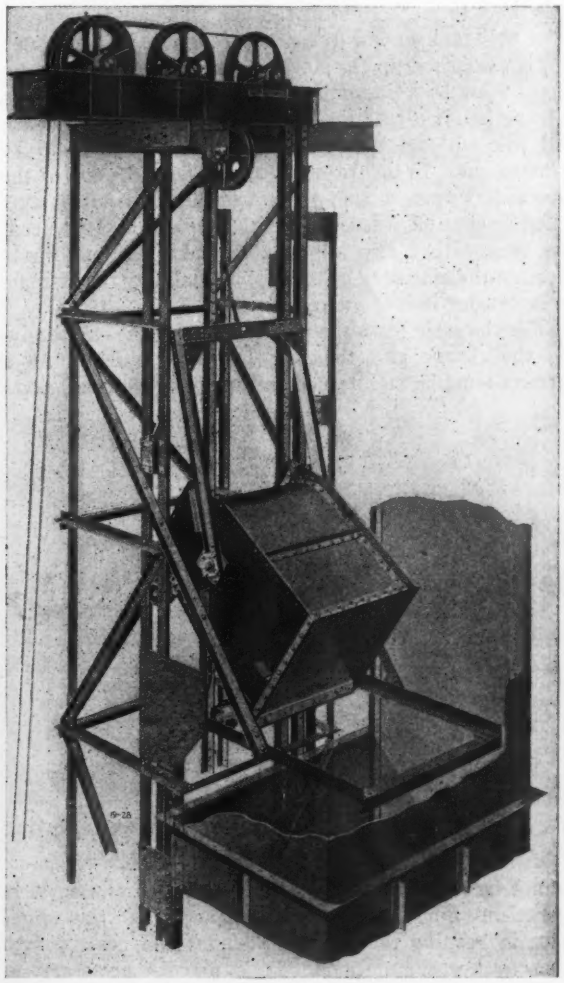


FIG. 6. SKIP HOIST ELEVATOR AT THE UPPER END OF ITS TRAVEL

at rather high velocities by nature. Plants built along mountain streams, for instance, simply allow their ashes to drop from the grates through a chute into the stream or sluice where they require no further attention. Hydraulic conveyors are sometimes used on board ship where cleanliness is given first consideration. The operation is costly, however, as large amounts of water have to be handled with the expenditure of a great deal of power. Mistakes have been made by trying to operate such a system in a land power plant where the pumping charges are far beyond reason.

The vacuum and steam jet systems are alike in many details. A pipe line is laid along the row of boilers adjacent to the ash clean-out doors. There is an opening in the pipe, provided with a suitable air-tight cover under each door where the ash is introduced into the

line. A current of high velocity air (about 225 to 250 ft. per min.) in the pipe carries the particles of ash in suspension to the point of discharge.

In the vacuum type, this velocity is imparted to the air by an exhauster, located beyond the discharge, which maintains a vacuum of about 2 in. in the system, depending on the length and resistance of the piping. The ash is discharged into an air-tight bin against a baffle and falls inert to the bottom of the bin. The air is removed from this tank at low velocity through a dust collector and is exhausted up the stack, if convenient, or to waste. There must be a current flowing at all times while ash is being handled because, if the air stops moving, the ash will pile up and clog the pipe, and will have to be rammed out. To insure continuity of flow, the end of the pipe is left open so that the air supply will not be curtailed or shut off when the intake is clogged. It is needless to say that any appreciable leaks will materially decrease the efficiency of the system and may, in extreme cases, render it inoperative.

For the same reason, openings between the one receiving the charge and the bin should be closed. As a vacuum must be maintained in the discharge tank, ashes

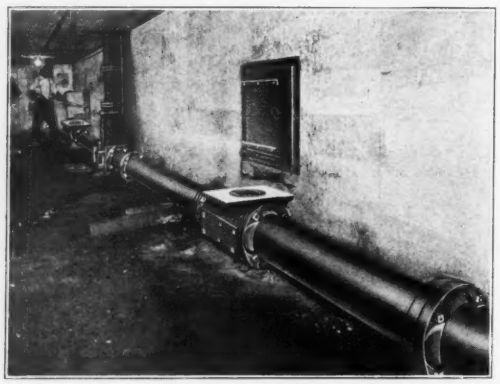


FIG. 7. A STEAM JET CONVEYOR INSTALLATION SHOWING THE INTAKE PORT UNDER THE ASH DOOR

cannot be removed from the bin while the system is in operation. Some trouble is experienced with this apparatus in keeping the exhauster blades and bearing free from dust accumulations. It is usually necessary to overhaul the fan thoroughly about once a week. It is necessary in the interests of safety to spray the ashes with water as they enter the bin to extinguish the live embers. This saturates the pile with water which freezes in cold weather, making it difficult to dispose of the ash. The power requirements for this system are peculiar in that the length of piping or the height to which the material is raised has, for the ordinary power plant, practically no influence. It is generally assumed that the horsepower necessary varies as the area of the duct. Power is being consumed continually while the current is flowing, regardless of whether material is being handled or not, so that it is expedient to have a constant feed of ash.

In the steam system, Fig. 7, a jet of high velocity steam is directed down the center of the piping from a suitable nozzle in a tee, inducing a pressure difference along the pipe which in turn produces a high air velocity. Where boosters are required along a stretch of straight piping, two converging jets are used, one from each side of the pipe, that give a resultant in the direction of the flow. This system does not require an air-tight receiver as in the case of the vacuum system, the bin being left open to the atmosphere to allow the air to dissipate itself. Frequently the ash is blown directly into the ash car, or sometimes, where dust is not particularly objectionable, onto a pile in the open. When comparatively cold ash is handled, the steam in the current is sufficient to extinguish any embers; but usually the discharge is sprayed with water as in the other system. The steam requirements vary widely in different installations depending on the skill with which the system is handled, and on its age. The steam consumption of the jets increases with age as the nozzle wears larger. Where boosters are employed, the cost of operation increases proportionately.

The length of pipe and the elevation have little effect as in the other system. The power required varies from about three boiler horsepower per ton of ash handled per hour up to eight and nine, depending on the size of pipe and rate of feed.

The abrasive action is heavy in both of these systems, especially at the turns. For this reason, the piping is made of special hard castings and usually located where it is readily accessible for making renewals. The piping is turned periodically so as to produce an even wear on all sides.

These systems are quite flexible and can be installed in the most cramped quarters, but the number of bends should be kept down to the absolute minimum.

GRAVITY

IN SOME large plants, the boilers are located on the second floor with ample ash pits underneath. A railroad track is provided on the ground level under these hoppers so that the ash can be dumped directly into the cars. This is a simple and successful method of handling the refuse from a large plant, where the boilers are on the second floor, but is not applicable to all installations.

ACCORDING to Prof. Schoch, of the University of Texas, lignite can be used as an efficient fuel when properly carbonized. Lignite is a half formed coal, which occurs in large quantities in Canada and also in the United States as far down as Texas. It is regarded as having great possibilities as a fuel, especially after it has undergone a coking process. The Canadian Government has appropriated $600,000 for experiments in its development as a fuel. Prof. Schoch recently reported on a series of experiments made by him, which show that by the carbonizing of lignite a coke of the highest heating power can be obtained, as well as a gas immediately usable in city mains for illuminating purposes, and a considerable amount of tar.

EXPERIENCE of over 50 yr. proves that there is no more justification in the claim that babbit metal of a particular brand or formula will satisfactorily function in all kinds of types of bearings, than there is in the claim that a particular medicine will cure all the ills that mankind is heir to. Babbit should be fitted for the needs of each particular case.

Effective Heat Transmission Surfaces

DEPOSITS OF SOOT AND SCALE EFFECT
COSTLY INSULATION ON BOILER TUBES

THE FUNCTION of the steam boiler is to utilize, in the evaporation of water, the heat furnished by its furnace. In order to accomplish this result efficiently, it is provided with tubes or flues to expose as large a surface as possible to the action of the heat. Boilers are usually rated at 10 sq. ft. of heating surface per horsepower developed. This is purely an arbitrary figure and is subject to wide variation. It implies nothing as to the limiting amount of water that a certain surface will evaporate. The resistance to heat flow of the bare metal is so small as to be almost negligible and it is generally assumed that the tube will take care of all the heat that reaches its dry surface. A unit area of heating surface is capable of transmitting a quantity of heat depending on the conductivity of the material, character of both surfaces, temperature difference between the fluids on either side, the arrangement of the tubes and the degree of turbulence of both the water and the gases. One square foot of heating surface in the first pass of a boiler, directly over the incandescent fuel may evaporate 75 lb. per hour while the same surface in the breeching will evaporate less than one pound per hour. The average mean rate is about 3 to 3½ lb. per sq. ft. per hr. from and at 212 deg. F. which is the equivalent of about 10 sq. ft. per boiler horsepower. The maximum evaporation is limited only by the amount of fuel that can be burned on the grate. In locomotive practice, a mean evaporation of 23 lb. has been accomplished and 20 lb. is recorded for torpedo boats. In such installations, the highest efficiencies have not been maintained; but efficiency is a consideration second to capacity in these cases.

Capacity is, however, dependent on something besides extent of heating surface and that is the condition of the heating surface. Absolutely clean surfaces are practically impossible in practice. Soot and scale are being deposited all the time; as soon as one layer is removed another is started, and the first layer is always the most costly per unit thickness. There is besides this a layer of quiescent gas on one side and a layer of water on the other that is held in the crevices of the scale, both of which act as heat insulators. These conditions limit the rate of evaporation for any given setting.

Heat is supplied to the surfaces by both radiation from the incandescent fuel bed and the brickwork and by convection from the moving furnace gases. The heat is transferred through the tube and the adhering soot and scale by conduction. It is then imparted to the water by convection again.

The amount of radiation depends on the difference in temperature between the fuel bed and the surface of the tube. According to Stefan and Boltzman, the amount of heat transferred is proportional to the difference of the fourth powers of the absolute temperatures of the two bodies. According to this the radiation increases rapidly with increases in furnace temperature. If, for instance, the furnace temperature is increased from 1200 deg. to 2400, or doubled, the radiation is increased by nearly 10 times. In the usual boiler having an average area exposed to radiation, the evaporation from the furnace section is about 30 per cent of the work done in the boiler while the other 90 to 95 per cent of the surface is utilized to do the remaining 70 per cent of the work. It will be seen that capacity could be greatly increased by using more of the radiant energy.

The three methods of heat transfer never operate separately. They are always combined and it has, therefore, been impossible to arrive at any expression for the heat transferred by any one method alone. An empirical formula that gives the total heat transferred has been adequate.

$$A\,U\,d = WC\,t$$

where A = sq. ft. of heating surface
U = mean co-efficient of heat transfer B.t.u. per hr. per sq. ft. per deg.
d = mean temperature difference between the flue gases and tube surface
W = lb. of gases per hour

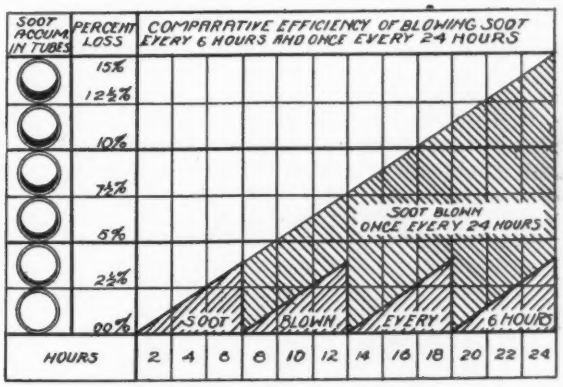


FIG. 1. THE COMPARATIVE SAVING EFFECTED BY DUSTING BOILER TUBES, IN ONE CASE EVERY 6 HR., IN THE OTHER, ONCE EVERY 24 HR.

C = mean specific heat of the gases
t = temperature drop between furnace and breeching.

U varies from about 30 in the first pass to about 5 in the uptake. The Babcock and Wilcox Co. gives the value of U for 100 per cent rating as

$$U = 2 + 0.0014 \frac{W}{a}$$

where a = average area of the gas passage through the setting.

In order that heat may be transferred by convection, it is necessary for the particles of the hot gases to come into direct contact with the heating surfaces. When the gases are in a quiescent state in contact with the tubes, heat transfer is hindered. There should be turbulation so that when one particle of gas has come in contact with the surface and given up its heat it will be immediately displaced by other particles of hot gas. In other words, a good scrubbing action is desirable on both water and gas surfaces of the tube. This result can be

accomplished by increasing the velocity of the gases through the setting and by introducing suitable baffles in the path of the gases. Well placed obstructions are usually well worth the extra draft required to overcome the added resistance.

It is manifest that thick tubes will transmit less heat than thin ones, consequently tubes should be as thin as is consistent with safety. It is also evident that either

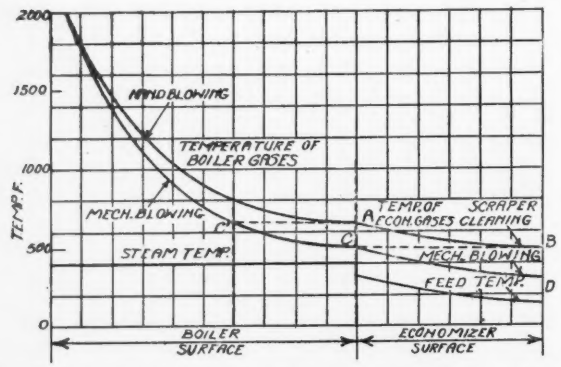


FIG. 2. TEMPERATURE OF GASES OF COMBUSTION IN A BOILER AND ECONOMIZER SHOWING, IN THE UPPER CURVE, THE EFFECT OF HAND BLOWING AND SCRAPING AND, IN THE LOWER CURVE, THE EFFECT OF SOOT BLOWERS IN BOTH UNITS

scale or soot will decrease the efficiency of transmission. Scale and soot incrusted tubes have a lower conductivity than thick tubes because the co-efficient is less for these substances than for iron. No accurate data is available on the subject, due to the widely varying composition

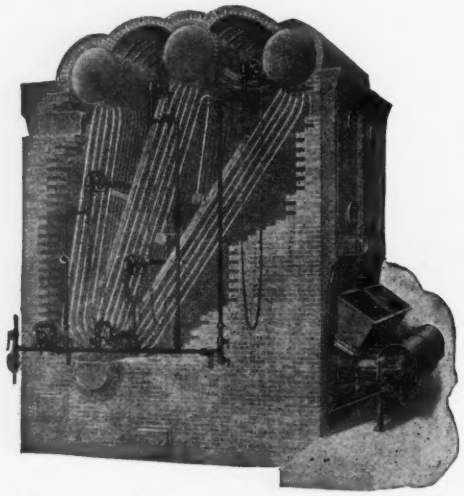


FIG. 3. A TYPICAL SOOT BLOWER INSTALLATION ON A WATER-TUBE BOILER

and texture of these deposits; but it is generally assumed that a clean tube ⅛ in. thick will transmit about 40 times as much heat as the same tube covered with 1 in. of soot. Put in another way, this means that the insulating property of 1 in. of fine asbestos is about equal to that of 1/5 in. of soot.

Basing the losses at zero for a clean tube, a 1/32-in. layer of soot will cause 9.5 per cent loss; 1/16-in., 26 per cent; ⅛-in., 45 per cent; 3/16-in., 69 per cent. From these figures, it will be seen that frequent blowing down of the tubes effects a big saving. Figure 1 will convey some idea of the relative merits of blowing off the soot, in one case, every 6 hr., and in the other, once every 24 hr. It is probable that the resistance to heat flow does not increase along a straight line as shown in this diagram, but follows a curved line that falls off from the straight line as the time increases.

Several methods are used in the removal of soot from heating surfaces. The steam lance is simply a nozzle connected by a flexible hose to a steam supply. This nozzle is inserted through the inspection doors in the setting and directed against the tubes. The jet action of the steam blows the soot from the tubes. This method is not particularly effective in that all the tubes cannot be reached, and the accumulation is merely blown from one section to another. Besides this, doors have to be opened during the operation which admits large quantities of excess air. This is a grimy and dirty job and is therefore usually slurred over by the operator.

Economizer elements are cleaned by scrapers which fit around the tubes and move continuously up and down

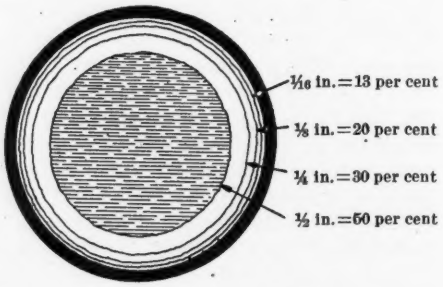


FIG. 4. DIAGRAM SHOWING THE AVERAGE ADDITIONAL FUEL REQUIREMENTS WITH VARIOUS THICKNESSES OF BOILER SCALE

against the surfaces. This system is good because it is continuous and the layer of soot is kept to a minimum, but the incessant rubbing hardens the deposit into a crystalline structure.

Water should never be admitted to the economizer under about 150 deg. F. because if it is less than this temperature, the tubes will sweat and this moisture will absorb the sulphur dioxide in the flue gases and form sulphurous acid which then absorbs oxygen to form sulphuric acid which has an extremely deleterious action on the tubes and breeching.

The installation of mechanical soot blowers is successful in keeping down the loss due to soot deposits. This blower is a pipe provided with suitable nozzles located along its length, that is put into the setting where it will be effective in dislodging the deposit. Several such pipes are put in in various positions so as to reach as much of the surface as is possible. These pipes are so arranged that they can be rotated to cover a large area. Figure 2 will serve to show how the flue gas temperature is lowered by the use of these three methods of cleaning. As this last method does not require that inspection doors be opened, there is no additional loss due to excess air. The apparatus is easily handled and its

operation therefore not as likely to be overlooked. Figure 3 shows a typical installation of such a system.

Mechanically operated soot blowers can readily be installed on a horizontal return tubular boiler. In some cases, a nozzle is fitted in the front end of the boiler opposite each flue and thus each flue has its own individual blower. In some instances, the nozzles are fitted in a tube that can be swung around to bring a nozzle opposite each flue in turn. It is impractical to blow a flue longer than 18 ft. unless exceedingly high pressure is used, because the force of the jet dissipates itself in that distance.

The following table gives the results of tests where in one case hand lances were used and in the other soot blowers.

	Test with Hand Lance	Test with Soot-Blower
Water evaporated per lb. of coal as fired, lb	8.06	8.72
Equivalent water evaporated from and at 212 deg. per lb. of coal as fired, lb	9.50	9.97
Equivalent evaporated from and at 212 deg. per lb. of dry coal, per cent	9.61	10.06
Efficiency, including grate, per cent	68.3	71.5
Saving of coal, per cent	.....	4.7

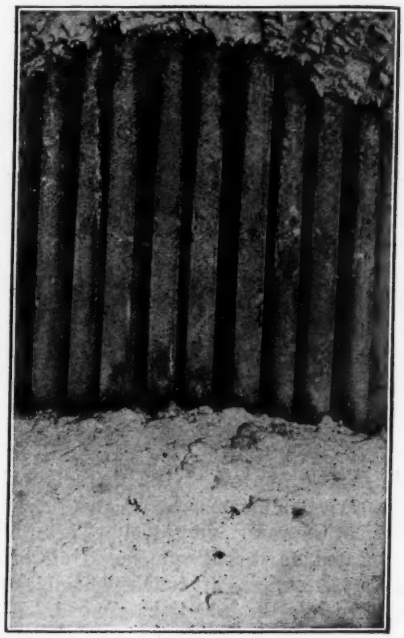


FIG. 5. A BANK OF TUBES THAT HAVE BEEN REGULARLY BLOWN DOWN

None of these methods can remove all the accumulation, so that it is necessary at certain intervals to take the boiler off the line, go into it and scrape and brush the inaccessible points by hand. Where soot is allowed to build up for any length of time, it becomes gummy and cakes so that in some cases it has to be taken off with a chisel.

Scale, the other insulator of heating surfaces, is met with just as frequently as soot and is on the whole probably more objectionable. Unless a boiler uses distilled water for the generation of steam, there is always a precipitate because all natural waters contain solids in solution. When the water is boiled, it goes off in the form of steam and leaves the solids behind. Thus the concentration in the water is gradually increased until the saturation point is reached where any additional matter is precipitated out. This precipitate accumulates on the heating surface and forms scale of varying composition and of varying physical properties, which is a poor conductor of heat. It is impossible to give reliable data on the amount of heat lost because of the varying composition. One manufacturer of scale cleaners states that the conductivity of a tube with a ¼-in. scale formation is about the same as that of a tube 1¼ in. thick. To give further idea of the loss incurred:

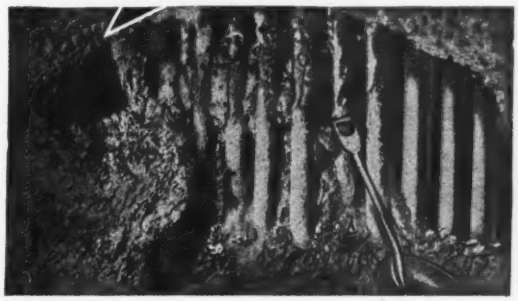


FIG. 6. TUBES THAT HAVE NOT BEEN REGULARLY BLOWN

Scale 1/16 in. thick requires about 13 per cent additional fuel.

Scale ⅛ in. thick requires about 20 per cent additional fuel.

Scale ¼ in. thick requires about 30 per cent additional fuel.

Scale ½ in. thick requires about 50 per cent additional fuel.

The following table gives the composition more in detail and the figures given are therefore probably more reliable.

LOSS OF EFFICIENCY FROM SCALE

Character of Scale	Thickness In.	Composition	Loss of Efficiency Per cent
Hard	1/50	Largely carbonate	5.4
Soft	1/32	Largely carbonate	7.2
Hard	1/32	Largely carbonate	8.5
Soft	1/25	Largely carbonate	8.0
Hard	1/25	Largely sulphate	9.3
Hard	1/20	Largely sulphate	11.1
Soft	1/16	Largely sulphate	10.8
Soft	1/16	Largely carbonate	11.0
Soft	1/16	Largely carbonate	12.4
Hard	1/16	Largely carbonate	12.6
Soft	1/11	Largely carbonate	15.0
Hard	1/9	Largely sulphate	15.9

When the loss is expressed in pounds of coal actually wasted per ton of coal fired the dollars and cents side will be more evident.

COAL WASTED BY SCALE

Average Thickness of Scale, In.	Coal Wasted Per Ton Fired, Lb.
1/50	100
1/32	140
1/25	180
1/20	200
1/16	220
1/11	300
1/9	320

The impurities in feed water are divided into two general classes, temporary and permanent hardness.

The composition of boiler feed water varies widely, but they usually contain some of the following: carbonates, bi-carbonates, sulphates, chlorides and nitrates of calcium, magnesium sodium and potassium and usually a small percentage of silica. Some waters contain

FIG. 7. AN EXAGGERATED CASE OF SCALE FORMATION

salts of iron, aluminum and manganese, but these are not so frequently met. All of these constituents have different degrees of solubility and some are therefore not as objectionable as others. The scale problem is met in several ways, by the water-softening process, by boiler compounds, and by scale removers.

The most logical method of meeting the situation is to remove the scale-forming elements before the water enters the boiler. These systems are of three general varieties, the hot water, the lime and soda and the zeolite processes.

The exhaust heater will precipitate most of the carbonates which constitute the temporary hardness. If soda ash is introduced, the salts forming permanent hardness will be converted into carbonates and will also be precipitated.

The lime and soda process does not eliminate all the scale forming salts, but it does remove a large part of both the temporary and permanent hardness.

The following table gives the amout of lime or soda ash necessary to remove the hardness due to one grain per gallon of the substance mentioned. For other amounts, the weight of lime or soda ash is proportionate.

Hardness of One Gr. Per Gal. Due to	Lb. Per Thousand Gal. of Water	
Calcium sulphate Ca SO_4 needs	0.111	soda ash
Calcium acid carbonate Ca $(H CO_3)_2$ needs	0.117	90 per cent hydrated lime
Calcium chloride Ca Cl_2 needs	0.137	soda ash
Magnesium sulphate Mg. SO_4 needs	0.140	soda ash
Magnesium sulphate Mg. SO_4 needs	0.098	hydrated lime
Magnesium acid carbonate Mg $(H CO_3)_2$ needs	0.28	hydrated lime
Magnesium chloride Mg Cl_2 needs	0.18	soda ash
Magnesium chloride Mg Cl_2 needs	0.123	lime
Carbon dioxide CO_2 needs	0.24	lime

In the zeolite process, water is passed over a bed of the natural or artificially manufactured zeolite mineral. The calcium and magnesium in the water coming in contact with zeolite are replaced by the sodium in the bed. When the sodium has been exhausted, the bed can be regenerated by passing over it a solution of common salt.

There is, however, always some precipitate in the boiler which should be blown or scraped off periodically.

Boiler compounds are used to minimize the bad effects of scale by changing the precipitates to a less objectionable character. Great care should be exercised in the selection of such a compound as it may easily do more harm than good. Another variety of compound is a substance which forms a sort of jel in the boiler. This jel surrounds the particles of scale as they are being precipitated and prevents them from cementing together. A sludge is formed that may be readily blown off.

Kerosene and petroleum oils are sometimes used to exert a rotting action on the scale, putting it into such a condition that it can be easily removed by tube cleaners.

A tube cleaner is a tool that is inserted in the tube to knock or scrape the scale from the surface. They

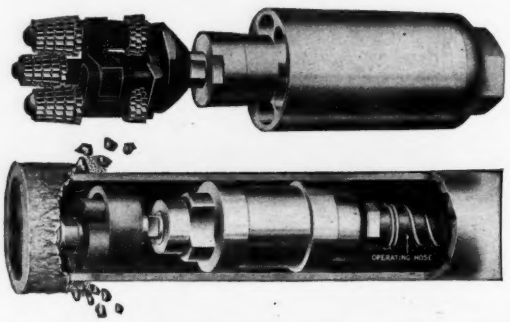


FIG. 8. TURBINE AND HAMMER TYPES OF SCALE REMOVERS

are made in two general styles, those that loosen the scale by a series of hammer blows and those which cut the deposit with a revolving tool. These instruments can be operated on steam, compressed air or hydraulic pressure that is supplied through a flexible tube which can be pushed into the tube to be cleaned. The hammer is actuated by a turbine or by a piston, that moves crosswise of the tube, the revolving tools are turbine driven. Figure 8 shows one variety of each of these two types.

To get the best results, these tools should be used regularly, the interval depending on the rate of formation of scale. Such an instrument should never be forced; it should be allowed to eat its way along the tube. When not in use, the cleaner should be cleaned and immersed in oil to keep in condition.

The saving in coal in a year's time effected by tube cleaners and soot blowers will usually pay for the cost of the installation. After this, any additional saving is clear profit.

Steam Wastes

WASTES DUE TO LEAKS, DRIPS, RADIATION AND EXHAUSTS EXPRESSED IN TERMS OF DOLLARS AND CENTS

A STEAM or water leak in the system of a power plant, insofar as the ultimate effect is concerned, is exactly the same as a hole in a man's pocket. Both result in a noticeable monetary loss. An engineer upon discovering a hole in one of his pockets through which his money was dropping would not lose much time in having the pocket repaired, no matter how careless or extravagant he might be and regardless of whether it was his own or somebody else's money he was losing. In this respect, all engineers are consistent. Not all engineers, however, upon discovering a leak in a steam or water line in their plant employ the same degree of rapidity in repairing the leak as they would the hole in their pocket. Yet, in the latter case, money is going to waste just as surely and perhaps even more rapidly than in the former. It must not be inferred that the engineer's attitude towards the steam or water leak as described above is intentional—that he is willfully allowing his employer's money to go to waste. As a general rule, engineers are conscientious about their work and try to make the best possible showing for the plant under their care. The fact is, that some engineers do not fully realize the importance of stopping and preventing small leaks about the plant.

A single small leak may not have the appearance of being of much importance when considered as an item of loss. Disregarding for a moment the question of whether such a leak is important or not, let us assume a number of such small leaks to exist throughout the plant. Small as each leak may be, the sum total of them all may put the situation in an entirely different light; they will indicate a considerable amount of waste. Considered from this angle, it will be found that considerable economy may be effected by eliminating leakage as much as possible.

A single leak, however, is capable of making its presence known at the coal pile. Let us assume a leak to exist at the flange joint in a steam line carrying steam at 150 lb. gage pressure. Let it further be assumed that this leak is equivalent in area to that of a hole 1/8 in. in diameter. The weight of steam escaping into the atmosphere can then be calculated by the following formula:

$$W = pa \div 70$$

Where W = the pounds of steam flowing per second, p = the absolute pressure in pounds per square inch, and a = the area of the orifice in square inches. Substituting the values of the foregoing example in the formula

$$W = (150 + 15)\ 0.012{,}27 \div 70 = 0.028{,}92$$

This corresponds to 104 lb. of steam per hour or 74,880 lb. per month.

A pound of steam at 165 lb. absolute pressure has a total heat value of 1195 B.t.u. Assuming the feed water to be heated to 210 deg. F. by exhaust steam, each pound of steam will require 1195—210 or 985 B.t.u. The total number of heat units in the steam wasted per month will then be $74{,}880 \times 985 = 73{,}756{,}800$ B.t.u. With a boiler and furnace efficiency of 70 per cent, the heat value in the coal necessary to produce the steam is $73{,}756{,}800 \div 70 = 105{,}366{,}800$ B.t.u.

Using coal of 13,500 B.t.u. per lb., we find that 3.91 t. of coal per month are necessary in order to supply the 1/8-in. leak with steam. The cost of the leak, assuming that coal can be obtained at $7 per ton, is $23.77.

This money is worth saving, no matter how much the plant as a whole may be earning, and when a number of such leaks exist in a plant, the necessity of stopping them becomes of vital importance.

The chart shown in Fig. 1 shows the amount of steam wasted by leaks of various sizes and for different steam pressures. By simply laying a straightedge across the two outside scales, which represent the diameter of the orifice and the steam pressure, the amount of steam wasted, in pounds per hour, may be read off the center scale.

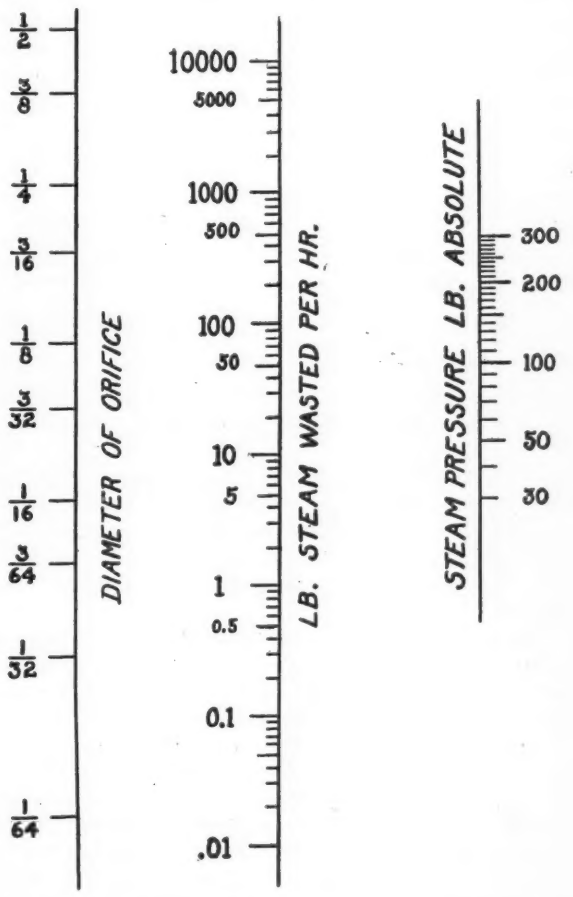


FIG. 1. CHART FOR DETERMINING QUANTITY OF STEAM WASTED BY VARIOUS SIZED LEAKS

Leaks, however, are not confined to steam lines alone. Leaks in water lines, particularly hot water lines, are ex-

pensive, and it can be shown that a leaky blowoff valve with water escaping from an orifice equivalent to a ⅛-in. hole, on 150 lb. boiler pressure costs about $40 per month for water and coal. Such a leak will allow 144,000 gal. of water to escape per month.

In addition to steam and water leaks, oil leaks, especially in plants using forced lubrication, are apt to cause considerable loss. All oil lines must be kept perfectly tight and should be examined frequently. Oil leaks are even more expensive than either steam or water, and in case a leak is discovered which cannot be repaired immediately, a receptacle should be placed so as to catch the drip, thus recovering the oil. A leak of a drop per second will drain a system of 34 gal. of oil per month if allowed to continue.

Cause of Leaks

Leaks may occur in pipe lines, fittings, tanks, stuffing boxes, boilers, condensers, etc., and may be due to a number of causes. If a joint is well made, and the pipe kept under the same state of pressure all the time, it should last for many years, but joints that are intermittently hot and cold, moist and dry, will cause the packing to dry out, crack and rot. If the pipe is cold the metal contracts, and if in a dry place the packing dries out and shrinks. If it is a steam joint, when the steam is turned on it will not be tight and the steam will work around the packing. Other causes of leaks in pipe lines

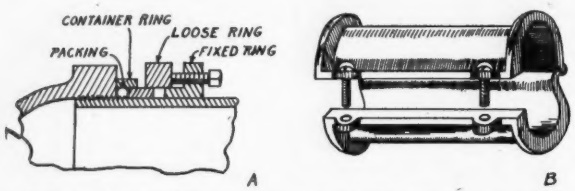


FIG. 2. (A) CLAMP RING FOR REPAIRING LEAKY JOINTS (B) PIPE CLAMP FOR USE IN REPAIRING A CRACKED PIPE

are as follows: Joints too far from supports, improper supports, insufficient supports, lack of provision for expansion, lack of proper alinement when "making up," insufficient bolts for flanges, poor threads, excessive vibration, gaskets too thick and poor quality or worn gaskets.

In engines and pumps, the stuffing-boxes may have a tendency to leak. While these may usually be tightened up while running, care must be taken not to set them up too tight or they may produce excessive friction or cause the rods to become hot. With well fitted metallic packing, there is little danger of excessive friction or leakage. If the packing starts blowing at times, it indicates that foreign matter has lodged between the rings. In this case, the packing should be removed, cleaned properly, and replaced; in replacing, however, care must be taken to replace all the rings in the same relative position they occupied before removal.

Worn valve seats should be repaired as soon as discovered, as it requires little time for them to be damaged beyond repair. Leaks in pipe lines at joints between pipe and flange can be stopped by applying a pipe clamp such as is shown in Fig. 2(a). Split seams or rust holes can be repaired by using a piece of sheet packing and the emergency pipe clamp shown in Fig. 2(b).

A loss of vacuum with condensing systems may be accounted for by leaks in exhaust valves of auxiliaries not in use, leaks around stuffing boxes of exhaust valves or other valves leading to the condenser, leaky low-pressure piston-rod stuffing boxes, leaks in exhaust joints or joints on condenser, defective air pump, etc. The maintenance of a high vacuum is important, particularly with a turbine since practically five-sevenths as much work per pound of steam may be obtained by expansion of steam between 2 lb. abs. and 1 lb. abs., as between 200 lb. abs. and 100 lb. abs. The desirability of reducing air leaks is therefore readily seen.

Inspection and overhauling of the various systems in the plant carrying steam, water, oil, air, etc., should be going on at all times. Repairs should be made as soon as the necessity becomes known. Systematic reduction of leaks and wastes will do more towards eliminating those "undetermined losses" in the plant than any other one thing.

Exhaust Wastes

THE correct method of utilizing the heat in exhaust steam in any power plant is of vital importance and in plants where the highest economy is desired, the problem should be carefully considered.

That exhaust steam, as it comes from an engine or pump at a temperature of 212 deg. F., has a high heat value is well known. It contains at least 80 per cent of the heat in live steam. The thermal efficiency of the steam engine or turbine is, at best, only about 20 per cent, and 80 per cent of the heat supplied to it in steam is rejected in the circulating water. In the condenser, however, the condensation of the exhaust steam produces a vacuum, and thus reduces the back pressure. This results in a great increase in power over that which could be obtained if the condenser were not employed, in which case the efficiency of the engine would be only about 10 to 13 per cent.

In plants where heating requirements do not exist, the gain in power secured by the reduction in back pressure, in the case of the main units, unquestionably justifies the use of a condenser. The exhaust steam from the auxiliaries presents quite a different problem and is one which deserves careful consideration.

It is the general impression that auxiliaries will take less steam if the exhaust is turned into the condensers, in this way reducing the back pressure. This impression is erroneous, however, and it will be found that vacuum is rarely registered on an indicator card taken from the cylinders of certain types of auxiliaries unless the exhaust connection is short and without bends. Long pipes and many angles affect the effect of the condenser. On the other hand, if the exhaust steam from the auxiliaries can be used for heating the feed water, all of the latent heat, with the exception of the loss due to radiation, is returned to the boiler and is saved instead of being lost in the condensing water or wasted with the free exhaust.

If there is an excess of exhaust, over that used to heat the feed water, it should, wherever possible, be used for heating buildings or for drying materials. One pound of steam used first in an engine or turbine and then in a heating system will replace about 1½ lb. of steam required where the engine or turbine is run condensing

and live steam is used on the heating system. If it is necessary to decide between running non-condensing the year around, using live steam for heating, the relative size of the heating and power loads and the length of the heating season must be considered. It is evident that where the power load is large in comparison with the heating load, the best arrangement will be a combined system. Where all of the exhaust of the engine or turbine can be utilized for heating during the heating season, it will pay to shut down the condenser.

Keeping in mind the advantages to be gained by heating with exhaust steam, it must be remembered that the first and most important use for the exhaust steam is to heat the feed water, since all of the heat of the exhaust steam so utilized is returned undiminished to the boilers.

Expressed in terms of coal used, heating feed water is 200 lb. abs. and the temperature of the water is 60 deg., changes are made so that the feed water can be heated to 210 deg. by exhaust steam. The total heat of steam above 32 deg. at 200 lb. is 1198 B.t.u. The saving in heat effected by the change will then be $(210 - 60) \div [1198 - (60 - 32)] \times 100 = 13.81$ per cent.

If the plant has a capacity of 1000 hp. and the amount of coal consumed per day is about 16 t., the amount of coal saved per year of 300 days is 662 t. With coal at $5 a ton, the yearly saving will be $3310.

The chart shown in Fig. 1 is based upon the formula used in the foregoing calculations and gives the percentage of fuel saved by heating feed water to various temperatures by exhaust steam. As may be seen, this chart consists of two sets of scales, A_1, A_2, A and B, B_1, B_2. The final result is read on the diagonal C. The use

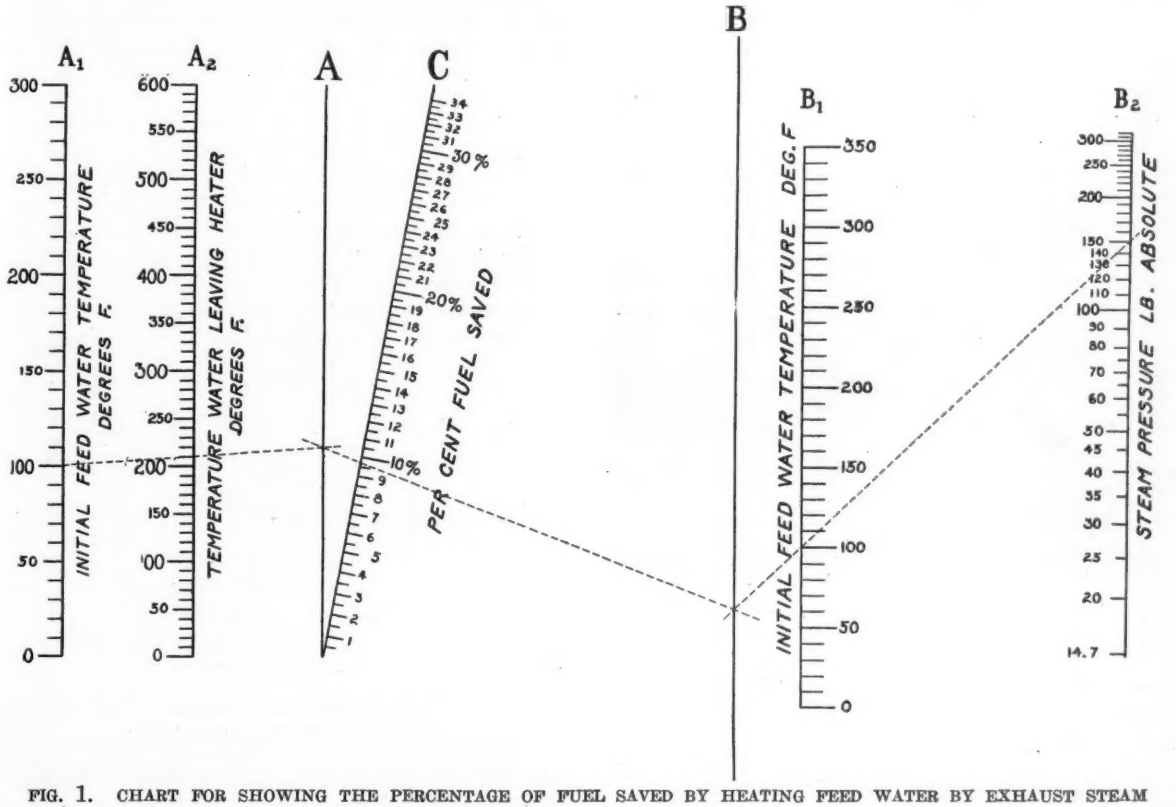


FIG. 1. CHART FOR SHOWING THE PERCENTAGE OF FUEL SAVED BY HEATING FEED WATER BY EXHAUST STEAM

by exhaust steam will result in a saving of about 1 per cent of the fuel used for every 11 deg. F. added to the feed water temperature. The gain in heat expressed in per cent, can more accurately be calculated by the use of the following formula:

$$S = (t - t_0) \div [H - (t_0 - 32)] \times 100$$

Where S = the per cent gain in heat due to heating the feed water, H = the total heat of one pound of steam above 32 deg. F., t = the temperature of the water leaving the heater, t_0 = the initial temperature of the water.

While this expression is not theoretically correct since it assumes a constant value of unity for the specific heat, whereas the specific heat varies with the temperature, the variation is so slight that it may be neglected for all practical purposes.

Suppose, in a certain plant, where the steam pressure of this chart may best be explained by means of an example. Suppose we have steam pressure at 150 lb. abs. and feed water with an initial temperature of 100 deg. F. The amount of fuel saved in this installation by heating the feed water to a temperature of 210 deg. may be found as follows: Lay a straightedge across 210 on scale A_2 and 100 on scale A_1. Locate point where the straightedge intercepts scale A. Now lay the straightedge across the steam pressure on scale B_2 and the initial feed water temperature on scale B_1 and mark point of intersection of straightedge with Scale B. Finally, by connecting the two points on A and B, as found above, the amount of fuel saved may be read off on scale C; in this case, 9.7 per cent.

The amount of steam which can be used for feed heating is fixed by the initial temperature of the feed water

and by the back pressure, usually atmospheric, carried in the heater. The full amount of steam required for bringing the water up to 212 deg. F. should be used.

If, when using exhaust from auxiliaries, there is sufficient steam at periods of heavy load, but an excess at periods of light load, the surplus auxiliary can be utilized in the lower stages of the main turbine or in the low-pressure unit of the main engine.

Use of Exhaust Steam in Industrial Plants

In manufacturing plants, a great amount of live steam is often used in various processes, the exhausts from which are wasted. Such exhausts, particularly in plants where there are a number of steam consuming units, may be utilized to good advantage, either for heating purposes or for power purposes.

By piping the various exhausts, from steam hammers, steam presses, etc., to a common receiver, steam can be delivered to low or mixed-pressure turbines. The photograph, Fig. 2, shows one of two 750-kw. turbo-generators being operated on exhaust steam at 3 lb. gage pressure,

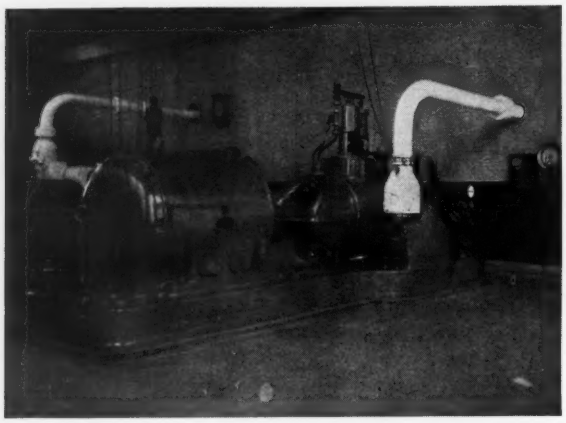


FIG. 2. 750-KW. TURBO-GENERATOR UTILIZING THE EXHAUST FROM STEAM HAMMERS AT 3 LB. PRESSURE

from a number of steam hammers. The 3500-hp. feed water heater in this plant is likewise supplied with exhaust steam from the hammers.

Heating by Exhaust Steam

In the beginning of this article, reference was made to the value of exhaust steam when used for heating buildings. In many cases, where a heating plant would have to be installed regardless of whether or not a power plant was necessary, it will be found that if a power plant is used in connection with the heating system, the power generated is more or less of a by-product. As a matter of fact, the value of exhaust steam for heating is such that in some plants where heating is necessary, engineers will run an engine idle, merely to secure exhaust steam for heating purposes. Thus, the engineer in a large Chicago office building keeps the lights on in front of the building all day in order to save coal. In other words, he finds it more economical to run an engine and use the exhaust for heating than to pass live steam through a reducing valve and then into the heating system.

Radiation Losses and the Advantage of Using Superheated Steam

PROBABLY the most effective method of obtaining conclusive evidence regarding the amount of heat radiated from bare steam pipes is to sit on one—that is, attempt to sit on one. As a means of impressing the fact in one's memory, this method is extremely effective, but is not to be recommended, however, since it is more or less painful and lacks technical demonstration. Perhaps, if we translate the heat lost by radiation from pipes into terms of dollars and cents, we can satiate our desire for knowledge on the subject just as well, and without any physical after effects.

The amount of heat radiated from any surface depends upon the difference in temperature between the surface and the surrounding air or other medium. If the air has the same temperature as the surface under consideration, no heat will be radiated. If the surface has a high temperature and the air a low temperature, heat will be transmitted from the surface to the air, and the amount of heat per square foot per hour per degree temperature difference so transmitted will increase with the temperature difference of the two mediums.

When it is considered that of the 100 per cent heat energy in the coal only about 14 per cent is available as effective power, the necessity for reducing the losses due to radiation in a power plant may be readily appreciated. All the rest is lost in friction, radiation and condensation. The diagram in Fig. 1 shows the distribution of the heat in coal when used under the boilers of the average steam power plant.

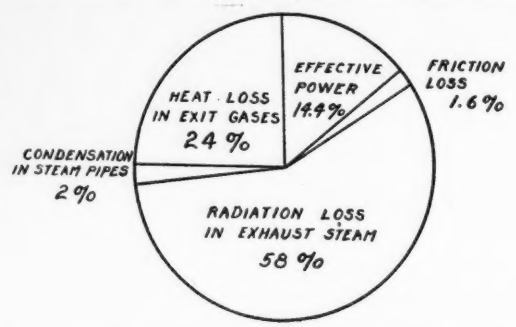

EFFECTIVE POWER 14.4%
FRICTION LOSS 1.6%
HEAT LOSS IN EXIT GASES 24%
CONDENSATION IN STEAM PIPES 2%
RADIATION LOSS IN EXHAUST STEAM 58%

FIG. 1. DISTRIBUTION OF THE HEAT ENERGY IN COAL AS USED IN A STEAM POWER PLANT

The quantity of heat radiated from bare steam pipes is often given as 3 B.t.u. per sq. ft. per hr. per deg. difference in temperature between the pipe surface and the surrounding air. This value, however, is correct only for certain conditions and it has been found that the pipe size and the temperature difference have an important effect upon this constant. Various investigators have measured this constant with a fair degree of accuracy and the chart shown in Fig. 2 gives values obtained by a number of investigators for the heat loss from bare pipes. These curves show that the constant may vary from 30 per cent below 3 B.t.u. per sq. ft. per hr. per deg. F. to values far above it. The chart in Fig. 3 shows a comparison between the loss from a bare pipe and the loss from a pipe covered with various thicknesses of 85 per cent magnesia.

Losses Due to Bare Piping

While it is generally known that the heat losses from bare pipes or other hot surfaces are considerable, the actual magnitude of such losses are not always appreciated. With steam at 150 lb. pressure, the amount of heat wasted by radiation from a 3-in. line 500 ft. long is represented by 191.5 t. of coal per year. At that pressure, each square foot of pipe surface wastes 840 lb. of coal per year. With coal at $5 per ton, this amounts to $2.10 per sq. ft. per year and for the entire line, the loss will amount to $960. The above figures assume surrounding temperatures of 70 deg. F. but in some cases where bare pipes are run out of doors the loss will be even greater.

The annual loss from 100 ft. of 5-in. bare pipe carrying steam at 150 lb. pressure, according to circular No. 17 of the Engineering Experiment Station at the University of Illinois, amounts to two cars of coal and 12 tank cars of water.

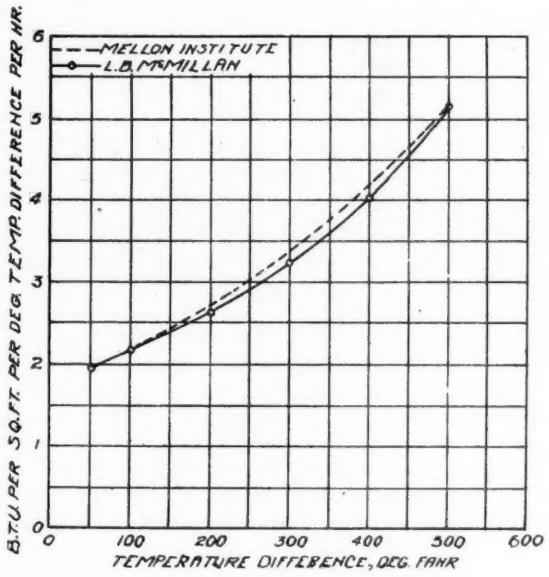


FIG. 2. HEAT LOSS FROM BARE PIPE

The examples given above are rather extreme and in practice the piping on systems of such size would be insulated in practically all cases. There are many fittings and flanges on such lines, however, which are not always covered, from which losses occur. An uninsulated flanged joint in a 5-in. insulated pipe line exposes approximately 0.75 sq. ft. of bare surface. If the line is carrying steam at 150 lb. pressure, the amount of heat lost by this joint will amount to 720 B.t.u. per hr. The coal represented by this loss per year will be 630 lb. If there are 20 such flanges on a line, there will be a loss of 12,600 lb. of coal per year, which, at $5 a ton, amounts to $31.50 a year.

L. B. McMillan in the Journal of the A. S. M. E. gives the accompanying table which shows the amount of heat lost from hot surfaces at various pressures and temperatures. From this, it will be seen that very little surface is required to lose the heat equivalent to a ton of coal. Even at atmospheric pressure, it requires only 7 sq. ft. of surface to waste this amount. The figures involving waste of coal in the table are based on an available heat value of 10,000 B.t.u. per lb. of coal, which is equivalent to a boiler efficiency of 70 per cent, using coal with an assumed heating value of about 14,000 B.t.u. per lb.

HEAT LOSSES FROM UNINSULATED HOT SURFACES

Ordinary steam temperatures; temperature of surrounding air, 70°F.					
Steam pressure (gage) lb.	Steam temp. deg. F.	Difference between temp. of steam & surrounding air, deg. F	Loss per sq. ft. per hr., B.t.u.	Waste of coal in lb. per sq. ft. per year	No. of sq. ft. of surface that wastes a ton of coal in 1 yr.
0	212	142	334	293	6.82
10	240	170	425	372	5.38
25	267	197	522.5	458	4.37
50	298	228	644	564	3.55
75	320	250	737.5	646	3.10
100	338	268	820	718	2.79
150	366	296	960	840	2.38
200	388	318	1079	946	2.12
250	406	336	1184	1036	1.93
Temperatures lower than 212°F					
Surface temp. deg. F	Difference between temp. of surface & surrounding air, deg. F	Heat loss per sq. ft. per hr., B. t. u.	Waste of coal in lb. per sq. ft. per year		No. of sq. ft. of surface that wastes 1 ton of coal in 1 yr.
100	30	56.6	49.6		40.3
120	50	97.5	85.4		23.4
140	70	142.0	124.3		16.1
160	90	190.0	166.3		12.03
180	110	242.0	212.0		9.44
200	130	298.5	261.5		7.65

The foregoing figures and the accompanying charts demonstrate conclusively that great savings may be made by the use of proper insulation on the lines. With a

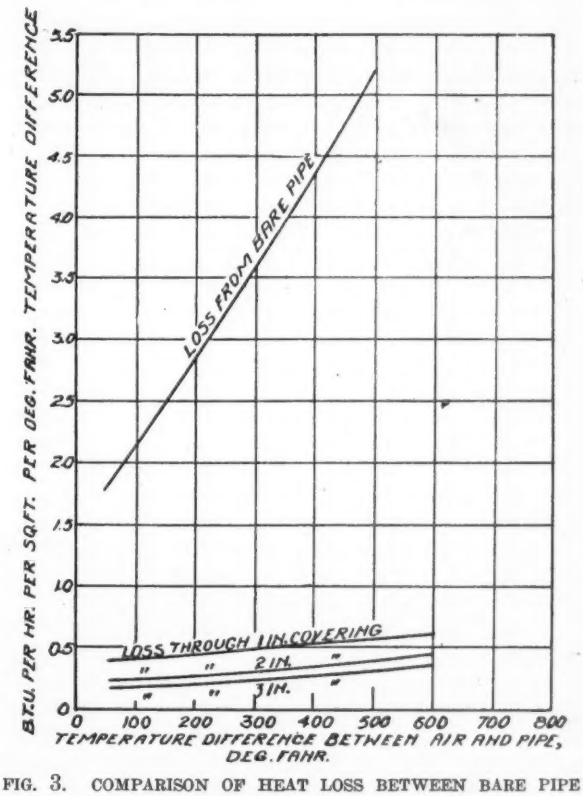


FIG. 3. COMPARISON OF HEAT LOSS BETWEEN BARE PIPE AND A 3-IN. PIPE COVERED WITH 85 PER CENT MAGNESIA

proper thickness of 85 per cent magnesia covering, the saving will in most cases repay the original cost of the installation in less than a year, and under constant operation at high temperatures where great thicknesses are

called for, the saving will often pay for the installation in as short a time as two months. By the use of the correct thickness of a good commercial insulation from 75 to 90 per cent of the heat loss may be prevented.

Tests of Boilers With and Without Covering

Results of tests on two boilers by Glen D. Bagley as described in the Journal of the A. S. M. E. show the value of insulation when applied to boiler surfaces. The exposed surface on the two boilers was 675 sq. ft. The tests covered a period of 24 hr. During the first test with the boilers uncovered, 10,784 lb. of coal were burned to evaporate 58,000 lb. of water. In the second test, after the boilers had been covered with 2 in. of 85 per cent magnesia blocks and plastic, 9296 lb. of coal were burned to evaporate 59,500 lb. of water. The evaporation rate during the first test was 6.35 lb. of water from and at 212 deg. F. per lb. of coal as fired, and during the second 7.55 lb.; 1500 lb. more water was evaporated with 1488 lb. less coal burned. This amounts to a saving of 15 per cent of coal burned due to covering the boiler alone, as pipe lines were not included in the test.

Value of Superheated Steam as a Factor in Reducing Radiation Losses

Radiation losses in pipe lines and fittings may be considerably reduced in many instances by the use of superheated steam. This is due to the fact that by its use, condensation is prevented in the lines. No moisture is carried over from the superheater and since the thermal conductivity of superheated steam, that is, its power to receive or give out heat to surrounding bodies, is much lower than that of saturated steam, heat is not transmitted so rapidly to the walls of the pipe and condensation is prevented. Even with a moderate degree of superheat, the steam can be delivered a considerable distance in an absolutely dry condition. It must not be inferred, however, that water cannot exist in the presence of superheated steam, as such an inference would be erroneous. It is possible for a pipe through which superheated steam is flowing also to carry water, but in practice, with well covered piping there is usually an entire absence of such water.

When a pipe is carrying saturated steam, the amount of heat radiated is usually represented by an equivalent condensation. Where such a pipe carries superheated steam, assuming no loss in pressure, the amount of heat radiated usually represents only a decrease in the amount of superheat, since condensation cannot take place until the temperature of the steam is lowered to that of the saturated steam at the existing pressure.

Long steam lines in existing power plants now carrying saturated steam can readily be made to carry superheated steam without any change whatever, with consequent increase in available heat and amount of steam delivered. In the generation of saturated steam, about nine-tenths of the heat absorbed by the water in evaporating it and in raising the steam pressure is latent heat. Therefore when condensation occurs in pipe lines the latent heat is liberated and nine-tenths of the heat is lost. If the condensate is not returned to the boilers, all the heat is lost. In order that all of the steam be transmitted to its destination without condensation losses, it is absolutely essential that its temperature first be raised to a suitable degree by means of a superheater.

The loss of superheat in such pipe lines varies with the size of the piping, the loss in small piping being much greater than in large pipes. Loss of superheat also depends upon the velocity of the steam through the pipe and the kind of covering used.

This brings us up to the point that higher velocities can be used to advantage in piping with superheated steam, as the steam is in the form of a gas and the friction of entrained moisture on the inside piping is done away with. This allows the use of a much higher velocity with a corresponding drop in pressure, or, in an existing line, the same amount of superheated steam would pass through the line to the point of use with considerably less loss in pressure.

This point should receive consideration in the design of new piping, as much smaller piping can be used than that required for saturated steam. This is especially true where the steam is delivered to a turbine or to other apparatus to which the steam flow is continuous. Velocities of 10,000 to 12,000 ft. per min. is common practice for this kind of use and much higher velocities are often employed. Where superheated steam is used in reciprocating engines, the velocity of the steam in the line cannot be so great, as the intermittent valve action of the engine may cause too much vibration in the line.

If the full advantage of high velocity in the piping is taken, the whole or a large part of the cost of the superheated installation may be saved by the reduction in piping, valves, fittings and insulation necessary.

Drip Wastes

WHEN SATURATED steam comes in contact with a surface the temperature of which is lower than that of the steam itself, it gives up some of its heat to the cool surface. Steam is exceedingly generous in this respect and if no attempt were made to insulate the pipes, the steam would part with the greater portion of its heat before reaching the engine or turbine. We have, however, no such thing as a perfect heat insulator, therefore no matter how thoroughly we cover the steam headers with insulating materials, we cannot compel the steam to retain all of its heat.

The transference of heat in this manner is the result of condensation in the pipes. Even with the best coverings, this loss approximates one-sixth of a pound of steam per square foot of pipe surface per hour for steam pressures of 100 lb. and with bare pipes it runs as high as a pound per square foot. In addition to this water of condensation, from ½ to 2 per cent of moisture is carried over by the steam from the boiler. Water in the lines means trouble and to avoid trouble we, therefore, insert separators and traps in the system to remove the water of condensation.

Having removed the water from the lines, the next question that comes up is, what shall we do with it? Some engineers pipe it to the sewer and let it go at that. Such practice, from a sound engineering standpoint, is nothing less than criminal; for two reasons. First, this water, usually spoken of as drips, contains a considerable number of heat units which represent coal and coal costs money; second, the condensate is pure water—distilled water, so to speak, and pure water should go back into the boiler, not into the sewer.

It is for the purpose of removing the condensate and returning it to the boiler or hot well that drip systems are installed in connection with power plant piping. All drips should be recovered and returned to the boiler, including those from oil separators. Usually the drips from oil separators are thrown away, but this is a mistake. A good oil separator, if properly installed, will remove about 90 per cent of the oil.

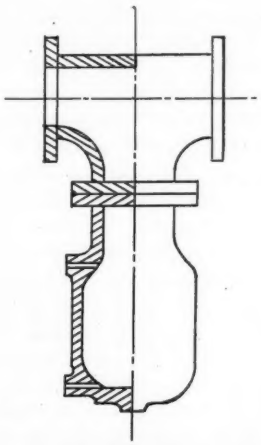
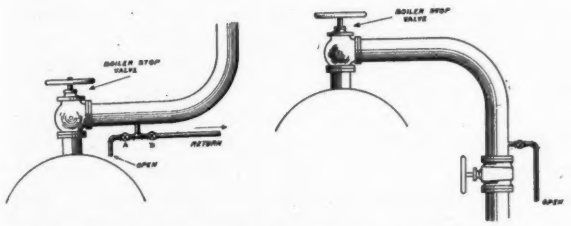


FIG. 1. DRIP POCKET FOR USE ON STEAM LINE

Drip systems on saturated steam systems are of greater importance than when used on a superheated steam system, since superheated steam does not give up its heat so readily and less condensate is formed. It is sometimes claimed, however, that when using superheated steam no drip system is necessary. This is an error, as there is no superheated steam conveyed but what there may be more or less condensation in the pipe.

Types of Drips

Drip systems may be divided into four classes: high pressure drips, low pressure drips, exhaust drips and combination drips. The latter type is occasionally met



FIGS. 2 AND 3. METHODS OF INSTALLING DRIP ON STEAM PIPES LEAVING THE BOILER

with when the load on an engine is of such a character that the pressure in the receiver alternates from a pressure of 30 or 40 lb. abs. to a vacuum of varying degree. High-pressure drips consist of those which are condensed practically under boiler pressure and include the steam condensed in steam pipes, cylinder jackets of engines, reheating coils of receivers and separators. Low-pressure drips include the steam condensed in exhaust steam feed heaters, exhaust steam piping, steam chests and exhaust heads. Vacuum drips are those in which it is necessary to remove the condensate from apparatus working under a vacuum.

Location of Drips

To drain long horizontal pipes properly, drip pockets, Fig. 1, should be provided every 75 to 100 ft. In general the drip pocket opening should be the full size of the pipe, as the water is likely to be carried over small openings. From the drip pocket a drain connection is made with a steam trap or other device or apparatus for returning water to the boiler. Wherever possible, horizontal pipes should slope so that drainage and the steam flow are in the same direction.

Supply pipes should slope from the header to the separators, and the engine supply should be taken from the top of the separator. The water from steam main drips can be gathered in a receiver and automatically pumped back to the boilers. The receivers used in connection with reciprocators serve both the purpose of catching the water and of collecting the steam. Such an apparatus must be large enough to reduce the vibration of the pipes which is caused by the sudden cutoff in valve motion.

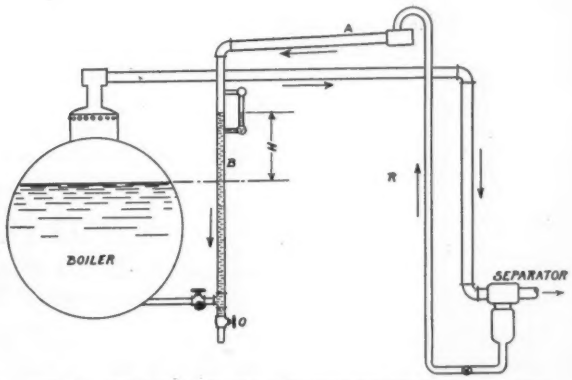


FIG. 4. STEAM LOOP FOR RETURNING DRIPS TO BOILER

In case the steam pipe, as it leaves the boiler, rises as shown in Fig. 2, drip should be installed at the lowest point just outside the stop valve. While the boiler is in operation, water may collect here. To prevent this, valve B should be closed and A opened so as to allow the condensate to drain off to the return system. When the boiler is out of operation, the valve A is closed and B opened. This drip should be so arranged that it may lead into the ashpit of the boiler where it can be observed. If the boiler is out of operation, this open-ended drip acts as a telltale in case the header valve is opened and is a safeguard for a man working in the boiler.

The pipe may, in some cases, drop all the way from the boiler as in Fig. 3. In this case, the drip should be installed as shown, and should leak to a visible open end. No drip is required while the boiler is in operation.

To prevent the accumulation of condensate at times when a valve is closed, a drip should be located inside of every valve in the steam mains. If the valve is in a vertical pipe with the flow downwards, the drip should be located immediately above the valve. This drip can be left open in case the valve is seldom shut. In cases of throttle valves, however, this drip should be trapped in order to keep the pipe clear of water although there are some cases in which it might be well to allow the water

to accumulate in the pipe and blow it into an open heater at starting time. Often, as much can be saved by letting the pipe fill and thus cutting down radiation wastes as by the return of the condensate to the boiler.

If a line rises beyond a valve, an open drip should be located between the valve and the vertical pipe. This will enable the operator to be certain whether the line is clear or not.

Method of Returning

Drips may pass through a common drip main to a receiver. If the steam header is located 5 ft. or more above the water line of the boilers, the returns may be by gravity, and lines should be run from the drip main into every boiler, either into an auxiliary feed line into the boiler drum or into a tee in the blowoff line. A stop and check valve should be placed in each of these lines.

Steam traps, "steam loops" and pumps may be used automatically to return the drip to the boiler. A steam trap is an apparatus made to dispose of the condensate from a piping system. The drip pipes from the system are run to the trap which discharges the water without allowing the steam to escape. While traps may differ considerably as regards design, they all effect the same purpose. When the discharge is against atmospheric pressure, as into a hot well, the trap is called a non-return type. When the discharge is against boiler pressure, the trap is called a direct return trap. Direct return traps must be located above the boiler.

The "steam loop" for automatically returning high pressure drips to boilers is shown in Fig. 4. The arrangement is simple, consisting of a horizontal and two vertical lengths of plain pipes as shown. The horizontal length A is left uncovered and serves as a condenser. Circulation is first started by opening the stop valve O at the bottom of the drop leg until steam escapes. The valve is then closed and the steam in the horizontal pipe A condenses and gravitates to the drop leg B. Due to the slight reduction in pressure in the horizontal, a mixture of spray and steam flows from the separator chamber to the horizontal, and, condensing, gravitates to the drop leg B. The column of water in the drop leg rises until its static head balances the difference in pressure in the riser R and the horizontal. A decrease in pressure in the horizontal, therefore, produces similar effects on the contents of the riser and drop leg but in a degree inversely proportional to their densities. If any more water tends to accumulate in the drop leg, the differences in pressure between that at the bottom of the column and that in the boiler cause the water to flow into the boiler until a balance is again secured. The process is continuous, and when once started requires no further attention. The Holly Loop is a modification of the steam loop in which all condensation from various points of drainage first gravitates to a receiver.

Load Regulation

Planning Operating Schedules; Forcing Vs. Extra Capacity; Dispatching Equipment; Block Plants

IN EQUIPPING a power plant, the size and capacity of the units to be installed is limited only by the maximum demand which may at any time occur. Unfortunately, except in few instances, such maximum demand is of comparatively short duration and frequently is considerably greater than the average load, thus necessitating the installation and operation of either excess equipment or units which normally are in service during but short periods of time. As a consequence, low load factors result and unwarranted capital overhead charges have to be carried.

In central station service, much improvement of load factor has recently been accomplished by the taking over of industrial motor loads to fill out the valleys between the lighting peaks. Even with this arrangement, the yearly load factor of the average large central station may vary from 35 to, perhaps, under most favorable conditions, 90 per cent; while in some industries as, for example, in textile mills which operate but 10 hr. per day 300 days each year, the average load factor obtainable is but little in excess of 40 per cent. As, however, the number of hours worked per day and the number of days worked per year increase or, as the characteristics of the load become similar to those of the central light and power station, the load factor increases in like proportion. Reports indicate a load factor of 93 per cent for a textile mill operating 24 hr. for each of 300 yearly working days. For other industries, the average combined light and power load factors may be expected to approximate the following values: For breweries, 45 per cent; for boiler shops, 18 per cent; for candy factories, 18 per cent; for engraving and printing establishments, 19 per cent; for foundries, 15 per cent; for glove shops and laundries, each 25 per cent; for hotels, from 25 to 50 per cent; and for woodworking factories, about 28 per cent.

Thus it is evident that in the majority of industrial plants the equipment installed is operated at a desirable degree of efficiency during but comparatively short periods of time and that as long as such conditions exist, no great degree of economy may be hoped for. Nature of manufacturing processes employed and mode of operation are to a considerable extent, if not entirely, governing factors. While but little can be done to change the nature of the manufacturing processes so as to bring about an improvement in load factor, study and investigation will many times reveal changes which can with but little or no expense be made in the method of carrying on the manufacturing processes in a way conducive to a more steady and uniform load on the power plant. To succeed in any such movement, however, co-operation between the power-plant operating forces and the manufacturing departments is of primary importance.

Frequently manufacturing processes utilizing power, but not dependent upon manual labor to any appreciable degree, may to advantage be carried on at night or at any other such times as will provide a more uniform load curve. When, however, such process work requires an amount of low-pressure steam in excess of that capable of being furnished by engine, pumps and other high-

pressure steam-consuming devices operated during periods other than the regular work day, only such manufacturing process should be carried on as will utilize the steam available. Where fleets of electrically-propelled trucks are employed, the batteries of these may be charged during the night, thereby adding appreciable mechanical load and making available considerable low-pressure steam for heating and other purposes.

Let us assume that in Fig. 1 is shown a typical load curve of the boiler plant of a manufacturing establishment, the steam generating units of which (four boilers) are each capable of delivering a maximum of 6000 lb. of steam per hour and that the maximum demand is 24,000 lb. of steam per hour (this at maximum efficiency). The maximum demand, however, extends over a period of but 3½ hr., or from 9 to 10:30 o'clock in the morning and from 2:30 to 4:30 o'clock during the afternoon. At all other times, the load is much less than the rated capacity of the boiler plant and during the night less than rated capacity of any single unit. At all times other than during the hour of peak load, the plant either in whole or in part must of necessity be operated on anything but an efficient basis.

The total number of pounds of steam produced throughout the 24 hr. is 227,000 lb., the average output for the day is 9458.33 lb. per hour and the maximum 24,000 lb. per hour, thus giving a load factor (or in this particular case a capacity factor) equal to 100 times the quotient obtained by dividing 9458.33 by 24,000, or 39.3 per cent.

Assume further that by rearrangement of the manufacturing department operating schedule, some of the process work ordinarily carried on during the day has been made a part of the night work, giving a steam demand as shown by the broken line curve, Fig. 1. The total steam output of the boiler plant still remains at 227,000 lb.; but due to the change made, the maximum demand has been reduced from 24,000 to 16,000 lb. with a consequent load factor of 100 (16,000 ÷ 9458.33), or 59.1 per cent, or an increase of 19.8 per cent.

With a rated boiler capacity of 6000 lb. of steam per hour for efficient operation, four boilers were required during the peak load periods while after the change but three, each operated somewhat underloaded, can well carry the maximum demand. It is also quite apparent that the single unit required for the night work is made to operate nearer rated capacity than heretofore and therefore more efficiently.

The above is, of course, only a hypothetical case, but illustrates how, by rearrangement of the operating schedule of a manufacturing establishment, it may be possible to secure a distribution of load tending toward a greater degree of uniformity, a higher load factor, increased efficiency and reduced fuel consumption.

Forcing Vs. Extra Capacity

Because of the peak loads encountered to a more or less extent in practically all power-producing plants comparatively heavy (short-time) demands are required to be met. Two methods to meet these demands are ordinarily available; either by forcing the equipment beyond its rated capacity or by the installation of boilers, prime movers, auxiliaries, etc., of a size such as will render them capable of carrying the added short-time load. Each of these methods has its advantages and disadvantages and the one to employ is to a great extent dependent upon local conditions, and whether the fixed charges on the additional investment will be less than the loss in efficiency and added depreciation of the forced units.

Extra capacity requires not only the installation of more boilers, stokers, engines, turbines, auxiliary apparatus, etc., but also frequently and generally purchase or at least utilization of added land, structural additions to the power house and, as a rule, the employment of extra labor. By forcing, however, these elements of operation cost are eliminated; but in their stead appear such factors as somewhat reduced efficiency of equipment, unusual depreciation with consequent shortening of the life of the units involved and possibly the necessity of installing forced draft apparatus.

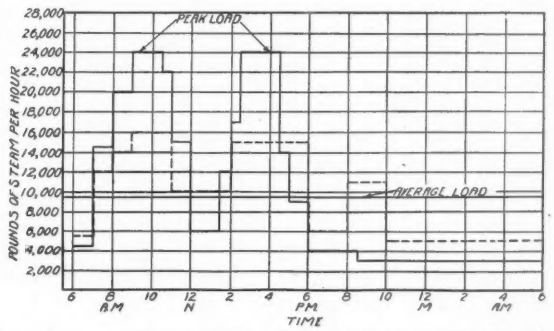


FIG. 1. TYPICAL BOILER PLANT LOAD CURVES SHOWING RESULT OF REDISTRIBUTION OF LOAD

Stokers in particular allow forcing and while the overfeed step grate and chain grate types can as a rule not well carry over 200 per cent of their rated capacity, underfeed stokers are today readily reaching 300 per cent and more.

Forcing is practically as effective in fire-tube as in water-tube boilers, the governing factor being the provided area of the disengagement surface and the volume of steam space.

The tendency of a boiler to prime under heavy loads is also a limiting factor in its ability to carry overload.

In referring to the forcing of steam boilers, Arthur D. Pratt (Mark's Mechanical Engineers' Handbook) states that, "The highest authentic capacity obtained with a standard stationary type of steam boiler, over a period of time of any duration, is 294 per cent of the boiler at the company's shop, Bayonne, N. J., with coal 10.14 lb. of water from and at 212 deg. F., per square foot of heating surface per hour.

"In a series of tests on a Babcock & Wilcox marine boiler at the company's shop, Bayonne, N. J., with coal fuel, an equivalent evaporation of 14.76 lb. per sq. ft. of heating surface per hour was obtained. This rate is equivalent to approximately 428 per cent of the boiler's rated capacity. In a test on the same boiler, but with oil as fuel, an equivalent evaporation of 15.83 lb. per sq. ft. of heating surface per hour was obtained or, on the ordinary stationary boiler basis of rating, 458 per cent of the boiler's rated capacity. In these two cases, a boiler horsepower was developed with 2.34 and 2.18 sq. ft. of heating surface, respectively."

Overloading Prime Movers and Generators

Limitations of design and mechanical construction render impossible the overloading of engines, turbines, generators and auxiliary apparatus to any appreciable extent. As a rule, steam turbines of the smaller sizes, that is, of capacities less than 300 hp., may be made to carry loads of from 115 to 130 per cent of the builders' ratings while machines of 300 hp. and more can be over-

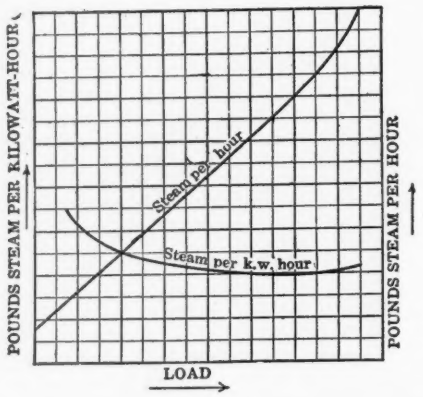


FIG. 2. STEAM CURVES FOR TURBOGENERATOR

loaded to an extent of from 10 to 25 per cent. Frequently overload valves are provided, enabling turbines to carry 20 to 30 per cent additional capacity.

To avoid confusion and misunderstanding concerning the capacity of a unit, it is now customary for some of the larger manufacturers of steam turbine generating sets to rate the turbine equipment on the basis of the maximum rating of the generator; consequently the apparatus should not be loaded above the rated capacity, as overloading will tend to affect the life of the unit due to injury to the insulation on account of overheating.

Overload capacity of electrical equipment such as direct- and alternating-current generators and motors and transformers is limited only by the load capable of being continuously maintained without excessive temperature rise. Ordinarily the allowable maximum temperature increase is 50 deg. C. (90 deg. F.), based upon a room temperature of 40 deg. C. (104 deg. F.). In the case of alternating-current machinery, normal excitation, voltage and frequency at a specified power factor, generally 80 per cent, are assumed.

Dispatching of Equipment in Service

Success in the economical operation of power plants is, to a great extent, dependent upon the care exercised in the selection of only those units which, under existing conditions, can maintain the water rate of the plant and therefore the number of pounds of coal required per kilowatt-hour at a minimum value. Characteristics of load and size, number and efficiency of units are factors requiring consideration and, while extensive tests and much research are necessary in order to secure desired data upon which to base the procedure to be followed, the expense and trouble incurred will be more than compensated by the increase in overall efficiency bound to result. In small plants containing but one or at most two units, continuity of service is of primary importance and difficulty will be encountered in attempting to operate at a minimum water rate, while in installations of medium and large capacity, particularly those in which the number of units is such as to allow considerable flexibility of operation, satisfactory results may be expected.

In one or two-unit plants, regular operation (assuming load and capacity of unit to allow such procedure) may well provide for the shutting down of at least one boiler, one engine or turbine and one of each of the auxiliaries for regular cleaning, inspection and necessary repair. In so doing the liability of failure becomes remote, and the forcing of the equipment, should emergency so require, becomes possible without danger of breakdown.

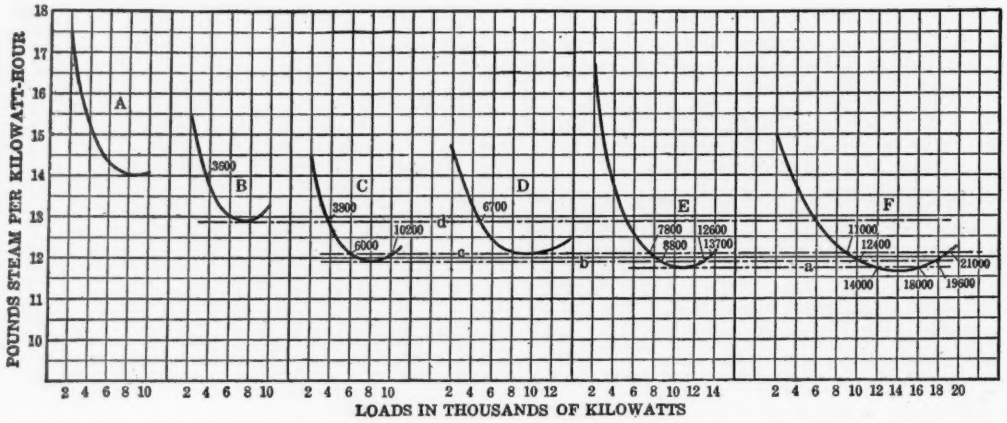


FIG. 3. WATER RATE CURVES FOR SIX TURBOGENERATOR STATION UNITS, SHOWING RELATIONS OF LOAD AND STEAM CONSUMPTION

Water Rates of Units

These are variable depending upon the steam pressure, the degree of superheat and vacuum; in the case of reciprocating engines, upon the setting of the valves, and the working condition of the valves, valve seats, piston and cylinder; and in the case of turbines, upon deposits on blading, wear of blading, variation of clearances and settlement in bearings. Obviously it is necessary to conduct tests for the determination of the water rate at regular stated intervals. Preferably this should be every six to eight weeks in plants operated continuously.

Shown in Fig. 2 is a typical turbine water (or steam) rate curve, and, as will be noted, the unit consumption decreases in value with increasing load, becoming practically flat and then slightly rising, thus indicating that at a given load the number of pounds of steam required per kilowatt-hour is a minimum. It is apparent, therefore, that in order to secure the highest degree of economy, operation of the unit should be kept, as much as possible, at or near loads corresponding to the lowest water rate.

The total steam curve is practically a straight line rising at a uniform rate until, at some given load, the increase of steam consumption becomes more rapid, resulting in a total curve of the form shown.

Operation at Minimum Steam Demand

Where all of the machines have practically the same water rate curve the highest degree of economy may be secured by distribution of the load among the various units so as to cause their operation at as near the points of minimum water as possible. Because of the comparative flatness of the lower end of the average curve, working at appreciable distances on either side of these points will have no decided effect upon the overall economy. With considerable decrease or increase of total load, however, the cutting out or in of additional units becomes desirable.

Generally the water rate curves of all the units are not alike and other procedures become necessary. Mathematical solution becomes possible although not entirely satisfactory for practical purposes. An alternative cut and try, although perhaps somewhat less accurate and more time consuming, but more satisfactory, method is in use by a number of engineers. The procedure to be followed is best explained by C. T. Hirshfeld and C. L. Karr in their paper "Economic Operation of Steam Turbo-Electric Stations" (Technical Paper 204, Department of Interior, Bureau of Mines). For purpose of illustration, a station containing six units designated as A, B, C, D, E and F, with water rate curves for given conditions approximately as shown in Fig. 3, is considered. Three of the machines referred to are 10,000-kw. units, two 14,000-kw. units and one 20,000-kw.

For convenience in reading, horizontal lines a, b, c, etc., have been drawn. Line a is tangent to the lowest point of curve E, showing the water rate of the unit second in economy; line b is tangent to the lowest point of curve C, that of the unit ranking next, and so on.

Assuming the minimum load ever carried to be 2000 kw., inspection of Fig. 3 reveals machine C with a rating at that load of 14.5 lb. per kilowatt-hour to be the one most satisfactory for the purpose. If a straightedge is placed across the figure horizontally at a height representing 14.5 lb. steam per kilowatt-hour and gradually moved downward while kept parallel to the horizontal axis, it will cut all curves at equal water rates. Comparison of load at different equal water rates on the several curves shows machine C capable of carrying any load from 2000 to 9000 kw. more economically than any other machine. Beyond this point, and up to 12,500 kw., machine E should be used, while from 12,500 kw. to 18,000 kw., machine F will prove to be most economical.

Next, it is necessary to decide whether loads in excess of 18,000 kw. can be carried more economically on F alone, or on some combination of the units.

Actual numerical trial will show that the greatest economy will be obtained by carrying load on F up to some point above 18,000 kw., but that somewhere between 18,000 and 19,000 kw. the load should be shifted to C and E, giving about 8000 to C and 11,000 to E, a combination yielding a water rate of approximately 11.8 at 19,000 kw., as against 11.85 for the same load on F alone. The point of change may be assumed at about 18,500 kw.

It is next necessary to discover how far to carry the load on the combination C and E. Inspection of the curve indicates that 8000 kw. on C and 12,600 kw. on E will give a total of 20,600 kw. with a water rate corresponding to the height of line b. Inspection also shows that 8800 kw. on E and 12,400 kw. on F will give a total load of 21,200 kw. with the same water rate.

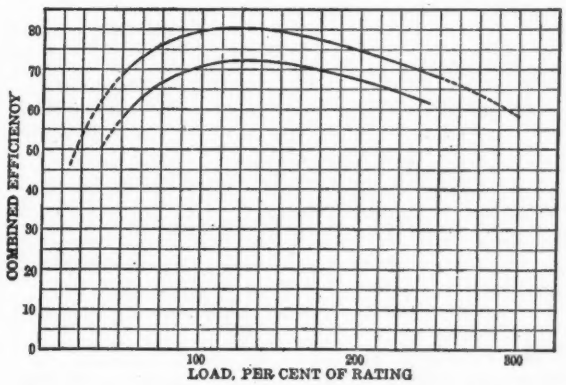


FIG. 4. CURVES SHOWING COMBINED EFFICIENCY OF BOILER UNIT AT VARIOUS LOADS

Obviously, the load would be carried on C and E from a total of 18,500 to about 21,000 kw., after which it would be carried on E and F to a total of 12,600 + 19,600 or 32,200 kw. The best distribution between E and F at each different load between 21,000 and 32,200 kw. must be found by cutting and trying, but it is evident from the curves that at loads between 11,000 + 14,000, or 25,000 kw., and 11,000 + 18,000, or 29,000 kw., the load will be held constant at 11,000 on E and the remainder will be taken by F.

Beyond a load of 32,200 kw. the possibility of using machine C must be considered because the water rate, when carrying that load on E and F in parallel, is the same as the best water rate on C. As a matter of fact, the load would have to be increased beyond 32,200 kw. before C is utilized with the water rate in question at a load less or greater than about 8000 kw.

This sort of analysis can be carried through in the way outlined until a loading schedule has been developed for all loads between 2000 and the maximum plant capacity.

Boiler Operation

As in the case of the turbine-room equipment, operation of the steam-generating units should also be based upon the characteristics of the apparatus, the curve used for the purpose, however, being that of the combined efficiency of the boiler unit at all loads liable to be en-

countered. A typical combined efficiency curve of a stoker-fired boiler representing, undoubtedly, exceptionally good practice is shown in Fig. 4. Under ordinary operating conditions, results would, perhaps, be about 90 per cent of those indicated.

In general, the shape of the curve will remain the same, thus allowing fairly great variation of load either side of that corresponding to maximum efficiency without any decided sacrifice in economy of operation. While under conditions of steady load it is obviously desirable to use such a number of boilers as will bring the load of each as near as possible to that corresponding to maximum efficiency; swinging or variable loads make it advisable to work the units so as to bring the average load to a point somewhat beyond the value. In so doing a higher average of efficiency will be maintained, because of the less rapid drop of the right-hand side of the curve.

8 boilers working at 62.5 per cent of rating;
7 boilers working at 71.5 per cent of rating;
6 boilers working at 83.5 per cent of rating;
5 boilers working at rating;
4 boilers working at 125 per cent of rating; or
3 boilers working at 166 per cent of rating.

Before any calculations can be made, it is necessary to know the fuel cost of banking and the heat value of the coal. Assuming, therefore, that it has been found by experiment to cost 0.2 lb. of coal per rated boiler horsepower-hour, that the fuel used has a heating value of 13,500 B.t.u. per pound, that the lower curve of Fig. 4 represents the characteristics of the boilers under consideration, and that a boiler horsepower is equivalent to 33,479 B.t.u., it becomes possible to tabulate the thermal costs for all the possible cases as shown in Fig. 5.

(1) OPERATION OF 10 BOILERS AT 50% OF RATING.

The curve assumed indicates an efficiency of about 57.5% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.575} = 174{,}673{,}000$

Heat supplied banked boilers per hour $= 0$

Total heat supplied per hour $= 174{,}673{,}000$

(2) OPERATION OF 9 BOILERS AT 55.5% OF RATING.

The curve assumed indicates an efficiency of about 60% of this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.6} = 167{,}395{,}000$

Heat supplied 1 banked boiler per hour $= 600 \times 0.2 \times 13{,}500 = 1{,}620{,}000$

Total heat supplied per hour $= 169{,}015{,}000$

(3) OPERATION OF 8 BOILERS AT 62.5% OF RATING.

The curve assumed indicates an efficiency of about 63% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.63} = 159{,}423{,}000$

Heat supplied 2 banked boilers per hour $= 2 \times 600 \times 0.2 \times 13{,}500 = 3{,}240{,}000$

Total heat supplied per hour $= 162{,}663{,}000$

(4) OPERATION OF 7 BOILERS AT 71.5% OF RATING.

The curve assumed indicates an efficiency of about 65.2% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.652} = 154{,}044{,}000$

Heat supplied 3 banked boilers per hour $= 3 \times 600 \times 0.2 \times 13{,}500 = 4{,}860{,}000$

Total heat supplied per hour $= 158{,}904{,}000$

(5) OPERATION OF 6 BOILERS AT 83.5% OF RATING.

The curve assumed indicates an efficiency of about 68.2% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.682} = 147{,}268{,}000$

Heat supplied 4 banked boilers per hour $= 4 \times 600 \times 0.2 \times 13{,}500 = 6{,}480{,}000$

Total heat supplied per hour $= 153{,}748{,}000$

(6) OPERATION OF 5 BOILERS AT RATING.

The curve assumed indicates an efficiency of about 71% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.71} = 141{,}461{,}000$

Heat supplied 5 banked boilers per hour $= 5 \times 600 \times 0.2 \times 13{,}500 = 8{,}100{,}000$

Total heat supplied per hour $= 149{,}561{,}000$

(7) OPERATION OF 4 BOILERS AT 125% OF RATING.

The curve assumed indicates an efficiency of about 72% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.72} = 139{,}496{,}000$

Heat supplied 6 banked boilers per hour $= 6 \times 600 \times 0.2 \times 13{,}500 = 9{,}720{,}000$

Total heat supplied per hour $= 149{,}216{,}000$

(8) OPERATION OF 3 BOILERS AT 166% OF RATING.

The curve assumed indicates an efficiency of about 70% at this loading, therefore

Heat supplied operating boilers per hour $= \frac{3{,}000 \times 33{,}479}{0.70} = 143{,}481{,}000$

Heat supplied banked boilers per hour $= 7 \times 600 \times 0.2 \times 13{,}500 = 11{,}340{,}000$

Total heat supplied per hour $= 154{,}821{,}000$

FIG. 5. TABULATION OF THERMAL COSTS OF BANKED BOILERS

Except in case of emergency, the character of the daily load may be at least approximately anticipated. When peak loads of considerable magnitude are expected to be handled by the boilers in service, it is preferable to operate at a point on the curve somewhat lower than usual. When, however, there is a marked dropping off of the load as is apt to occur, unnecessary banking of any of the boilers may be avoided by operating normally at a somewhat higher point on the curve than under steady load conditions.

Citing as an example a plant containing 10 boilers, each rated at 600 hp., Hirshfeld and Karr, in the abovementioned paper, show by the following method how best to determine the number of boilers to be banked for maximum efficiency, assuming that all 10 are operated at moderate loads above rating during the day and early evening, and that later the load on the plant drops to a point which requires but 3000 boiler horsepower. This load could be carried in any one of the following ways:

10 boilers working at 50 per cent of rating;
9 boilers working at 55.5 per cent of rating;

Obviously methods (6) and (7) are practically equivalent from a thermal viewpoint and are thermally more efficient than any of the other combinations. If no other considerations led to a different result, this plant should, therefore, bank fire on six boilers at night.

Operation of Auxiliaries

Features of design are usually the limiting factors in the flexibility of operation of auxiliaries, and, therefore, preclude any fixed rule or rules. In general, however, all required auxiliary power should be obtained in such manner as to provide only such an amount of exhaust steam as will be utilized for the heating of the boiler feed. All in excess of that amount must be secured from the main electric generating units if maximum economy is to be realized.

Block Plants

Where transmission distances are comparatively short and land values high, reduction of capital investment and related costs and labor charges, better load

factor and consequently increased overall economy are frequently possible by the employment of so-called block plants. This scheme, which primarily consists of the use of but a single power plant for the serving of a number of adjoining office buildings, hotels, theaters, manufacturing plants, etc., is found quite extensively employed in the congested districts of some of our larger cities. It is particularly well adapted and is, in fact, superior to central-station service where, in addition to an electric load, a demand for steam, hot water, air, refrigeration, etc., exists. Its exceptional worth is found where exhaust steam may be employed for heating or process work in adjoining plants or buildings where otherwise only steam generating plants would be required. In a steam power plant, a boiler and furnace efficiency of 60 per cent or more is obtainable, while in a heating plant the same efficiency seldom exceeds 35 per cent. The resulting economy is obvious.

Excessive distribution losses, heavy capital charges for transmission systems and auxiliary equipment, together with maintenance costs, are factors limiting the usefulness of the block plant. In addition, the utilities commissions of some of the states look upon this scheme as one akin to public service, treating it as such, relative to rates, standards of service, etc., and thereby discourage its more extensive use.

Location and Equipment of Plant

Block plants have, in general, come into existence by the gradual elimination of other inefficient plants although, in some instances as in the case of the Central Manufacturing District, Chicago, the plant installed may be especially designed for "block" service. Whether the plant to be installed is new or the result of rehabilitation, the location selected for it should, however, be one insuring ready means for fuel and water delivery and if possible in order to reduce distribution and transmission losses to a minimum at the so-called center of gravity of the load.

Prior to the specification of the equipment required, an extensive survey of load conditions, both electrical and steam (or in reality B.t.u.) for heating, process work, etc., is necessary. This survey should, in addition, embody the characteristics of the load throughout the 24 hr. of the day and in making the first decision as to the size of the equipment to be installed, due consideration should be given the possibility of future load growth.

Load characteristics of a typical small block plant are shown in Fig. 6 by the dot-and-dash line. Two office buildings are served, one being a 150 by 86-ft., 11-story structure and the other 112 by 50-ft., 12 stories high, the equipment used consisting of three water-tube boilers, three 60-kw. and one 80-kw. engine-driven generating sets, one 240-v., 240-amp.-hr. storage battery and a 10-ton compression type refrigerating machine.

The load characteristics of an apartment home are somewhat different from those of the office building as an inspection of the dotted line, Fig. 6, reveals. The peak, instead of occurring during the hours of daylight, comes on at about 4 o'clock in the afternoon, reaches a maximum between 6 and 9 o'clock and then gradually drops off. Serving this plant are three 150-hp. return tubular boilers, three 65-kw. generators direct-connected to high-speed engines and one 12-ton compression type refrigerating machine.

In installations of this kind sufficient exhaust steam is undoubtedly available to supply the demand. In hotel service, however, considerable steam is required (in addition to that used for heating) for cooking and warming apparatus and is dependent upon the kind of service rendered. From surveys made for the purpose it has been found (Willard and Harding, Mechanical Equipment of Buildings) that for cafeteria service an average of 3.65 lb. of steam are required per day for each person served, while for the highest class of restaurant service approximately 20 lb. are necessary.

Example of Advantages of Block Plants

Inspection of Fig. 6 showing the typical office building and apartment house load curves, respectively, reveals the fact that for the former, the bulk of the load is carried between the hours of 8 a. m. to 7 p. m., while during the remaining hours of the 24 the load is comparatively light, the load factor low and the resulting economy proportionately poor. On the other hand, the apartment house load is at a maximum during the evening only and as a consequence this plant also is forced to operate at an efficiency not the most favorable.

Assume these two institutions to be within such proximity as to render possible the use of a single block plant. The resulting load will then be as shown by the full line, Fig. 6, thus providing a higher load factor and

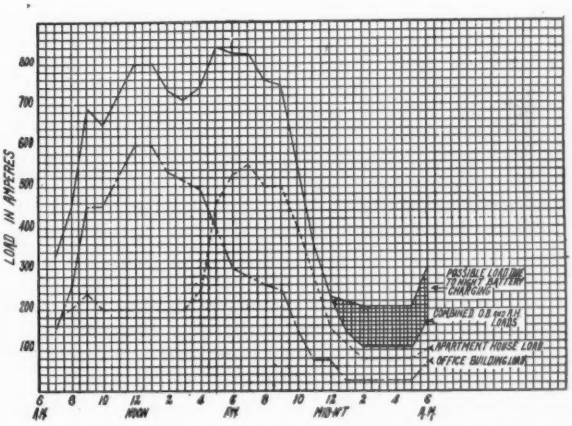


FIG. 6. LOAD CURVE ILLUSTRATING IMPROVED CONDITIONS OBTAINABLE BY EMPLOYMENT OF BLOCK PLANT

insuring operation of the plant at or near full rated capacity during a greater part of the day than is possible when but either one or the other institution is being served.

After 2 o'clock in the morning, the total load is comparatively light and undoubtedly but a fraction of the rated capacity of any single unit which might be found installed. A condition such as this can, however, be quite readily improved by the taking on of an extra night load as, for instance, the charging of storage batteries.

Selection of Equipment

Because of varying local conditions, no set rules can be advanced relative to the type and size of prime mover

equipment to be installed in any given plant. Each case requires consideration as an individual problem.

Assume in the case of the plants referred to above, that no new generating units were to be purchased but instead only such machines retained for block plant service as would be capable of carrying a maximum load as indicated in Fig. 6, with perhaps a reserve capacity of 15 to 20 per cent. The office building plant was equipped with three 60-kw., 240-v. machines and one 80-kw., 240-v. machine, while the apartment house plant contained three 65-kw., 240-v. units having a combined capacity rating of 1895 amp. From the load curves shown (which represent the heaviest load at any time to be expected), it is evident that the capacity available is considerably in excess of the maximum carried. Obviously, then, a number of units may be disposed of.

Each of the 60-kw. machines has a 250-amp. rating, each of the 65-kw. units a 270-amp. rating and the 80-kw. machine a 333-amp. rating.

The minimum light and power load is a trifle in excess of 100 amp., when carrying a battery, as indicated in Fig. 6, somewhat over 200 amp., while the maximum load is practically 840 amp. Adding 20 per cent to care for load growth an installed capacity of at least 1008 amp. would be required. Evidently, therefore, at least one of the 250-amp. (or 60-kw.) machines may well be retained for carrying the after midnight load, an arrangement allowing considerably greater economy of operation than would be obtained by the use of either one of the 65-kw. or 80-kw. units for this comparatively light load.

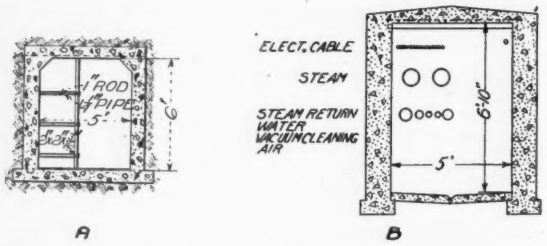


FIG. 7. TYPICAL TUNNEL SECTIONS

But, from 5 a. m. to 8 a. m., the load appears somewhat greater than could be well carried on the 60-kw. machine, still light for two 60-kw. units. Undoubtedly the 333-amp., 80-kw. set would prove better for this work particularly up to 7 o'clock, after which both the 60 and the 80-kw. machines might be run. As their combined ampere capacity is 583 amp., these two units could well carry the load up to 9 o'clock; then it would appear better to put on one of the 65-kw., 270-amp. units, making a total of 850 amp. available for service throughout the day.

From this, the installation of one 60-kw., one 65 and the 80-kw. units appear desirable with perhaps addition of an extra 65-kw. unit to care for possible load growth and for emergency service.

The number and size of boilers to be installed is, of course, also dependent upon the maximum demand (and its length of duration) for steam. That actually required for power purposes may readily be determined from the water rates of the engines and the maximum load which they carry. Whether the exhaust from the prime movers is of sufficient quantity and at the desired pressure for such service as heating, process work, etc., can only be determined by a thorough study and investigation of existing and probable future local conditions. With a total demand considerably in excess of that required by the engines, pumps, etc., the necessity of providing additional steam generating capacity is apparent; in such event the installation of pressure-reducing devices is undoubtedly necessary, especially where low-pressure, steam-consuming apparatus is to be served.

Distribution Systems

Although the original cost of overhead distribution systems for electric energy, water, steam, air, etc., may prove considerably less, particularly where but short distances are involved, underground tunnel systems are more satisfactory. They render easier the installation, alteration and repair of cables and pipe lines and eliminate the excessive condensation of steam occurring in overhead lines with low outside temperatures.

Two typical tunnel sections for the carrying of steam, water, air, electric lines, etc., are shown in Fig. 7. In that at A the weight of the structure is carried by a mat of reinforced concrete 8 in. thick, and in order to furnish ample room not only for passage but also to make repairs and changes when such become necessary, the tunnel has been constructed with a width of 5 ft. and a height of 6 ft. Top and side walls are each 10 in. thick and to insure stability and rigidity, the latter are joined to the supporting mat by means of a dovetail joint.

Along one side of the tunnel and on standards placed 12 ft. apart are carried the various pipe lines, while to the opposite wall are attached the electric lines. Each of the standards consists of an upright member, a 6-ft. length of 2 by 2 by 3/16-in. angle iron and three horizontal pipe carrying members, each a ¾-in. rod carrying a 1-in. pipe, thus providing a roller support. The uprights are secured in place by means of ½-in. pins embedded in the concrete and attached to adjustable legs bolted to the angle irons and as a means of reinforcement and proper supporting power the ends of the 1-in. rods opposite the angle irons are likewise embedded in the concrete.

The tunnel, which is shown at B, is constructed somewhat differently. It has sectional dimensions of approximately 5 by 7 ft., rests upon footings carrying 1-ft. side walls joined by a roof, also of concrete, having a maximum thickness of about 6 in. and reinforced with rods and I beams which also act as points of suspension for the pipe hangers. These consist of drop rods, the lower ends of which are fitted with cross-pieces made of piping and while not providing a roller bearing, reduce to a minimum the resistance offered any longitudinal movement of the piping caused by expansion and contraction. Each of the pipe lines is, in addition, fitted with a slip type of expansion joint, one of which is inserted about every 125 ft.

Where steam is conducted through long lines of piping provision must be made to care for the expansion and contraction bound to result. As a rule one of two means are employed. Either regular expansion joints are utilized or long turn bends of U shape installed. These, however, take up more space than is generally available in tunnel work; expansion joints are therefore preferable.

Transmission Wastes

SYSTEM LOSSES AND THEIR EFFECT UPON THE COAL PILE; WAYS AND MEANS CONDUCIVE TO INCREASED ECONOMY

MUCH FUEL may be wasted due to energy losses occurring through leakage and friction in pipe lines carrying water, air or steam; through slippage of belts and friction of bearings; and through excessive resistance and grounds in electric transmission and distribution systems.

Frequent periodic inspection of piping, fittings and valves is necessary if transmission losses of fluids are to be prevented. In the case of steam in particular, fuel wastes incurred through leakage may render an otherwise highly efficient plant exceedingly wasteful and expensive. As an example may be cited the losses due to leaking blowoff valves as indicated in Table I. Even with coal at but $2 per ton, the continuous leakage of steam at a pressure of 150 lb. per sq. in. through an orifice ¼ in. in diameter results in a financial loss of

TABLE I. LOSSES DUE TO LEAKING BLOWOFF VALVES

Size of Orifice Diam. Inch	100 Lb. Pressure				120 Lb. Pressure				150 Lb. Pressure				200 Lb. Pressure			
	No. Gal. Water Wasted Per No.	Cost of Coal Per No.	Cost of Wasted Water at $0.10 Per 1,000 Gal.	Total Cost Per No.	No. Gal. Water Wasted Per No.	Cost of Coal Per No.	Cost of Wasted Water at $0.10 Per 1,000 Gal	Total Cost Per No.	No. Gal. Water Wasted Per No.	Cost of Coal Per No.	Cost of Wasted Water at $0.10 Per 1,000 Gal.	Total Cost Per No.	No. Gal. Water Wasted Per No.	Cost of Coal Per No.	Cost of Wasted Water at $0.10 Per 1,000 Gal.	Total Cost Per No
1/2	1,908,120	$228.92	$190.51	$419.43	2,160,000	$268.61	$216.00	$484.61	2,304,000	$307.20	$230.40	$537.60	2,696,416	$399.29	$269.64	$668.93
3/8	1,094,400	121.41	109.44	230.85	1,254,240	155.93	125.42	281.35	1,342,800	179.04	134.28	313.32	1,875,975	268.13	187.59	455.72
1/4	476,280	57.23	47.62	104.85	540,000	67.15	54.00	121.15	576,000	76.80	57.60	134.40	674,104	99.83	67.41	167.23
1/8	119,070	14.31	11.90	26.21	135,000	16.40	13.50	29.90	144,000	19.20	14.40	33.60	168,526	24.95	16.85	41.80
1/16	29,763	3.60	2.96	6.56	33,750	4.10	3.37	7.47	36,000	4.80	3.60	8.40	42,131	6.24	4.21	10.45
1/32	7,440	.90	.74	1.64	8,437	1.03	.84	1.87	9,000	1.25	.90	2.15	10,533	1.56	1.05	2.61

Calculated by the engineering department of the Homestead Valve Mfg. Co. Formulas for this table taken from "Kent," Sturtevant "Mechanical Draft." Initial temperature of water taken at 150 deg. F., coal at $2 a short ton, delivered at furnace. 1 lb. coal = 13,000 B.t.u. Waste supposed to go on continuously.

$134.40 a month, while under a pressure of 200 lb. and an orifice diameter of ⅜ in. the total loss per month is $425.72 or the interest at 6 per cent on an investment of approximately $85,000. The necessity of maintaining a piping system free from leaks is thus obvious.

Excessive internal friction of piping or resistance to flow is also conducive to loss of energy and therefore to waste of fuel and while this element cannot be entirely eliminated proper design can reduce this source of loss to a minimum. Various rules and formulas have been devised to embody the results of experiments; but those which, on the whole, are most convenient and come nearest to representing the results are the ones prepared by Prof. Schoder of Cornell University. For new and clean pipes carrying water and having smooth surfaces, his equation becomes: Loss in head in feet per 1000 ft. of pipe $= 8.49\ V^{1.85} \div d^{1.25}$, and for old pipes the internal surfaces of which have become roughened by corrosion or accumulations of foreign matter, also for spiral riveted pipes, this changes as follows: Head lost $= 11.17\ V^{1.96} \div d^{1.25}$. In both equations, V represents the velocity in feet per second, and d, the actual internal diameter of the pipe in inches.

Since this equation is somewhat difficult of solution, the results have been embodied in the chart, Fig. 1, from which readings can be taken direct. The curves on the left-hand side of the chart give the amount of water in pounds, cubic feet, or gallons per minute, for any size pipe, at any velocity between 60 and 900 ft. per minute, the range usually permitted. The chart on the right gives the means of determining, by a straightedge, any one of the three factors—amount of water per minute, loss of head per 1000 ft. of pipe, or diameter of pipe—when the other two factors are known. If it is desired to know the loss in head for a 4-in. pipe carrying 20 cu. ft. per minute, the straightedge is passed through 20 on the cubic feet per minute scale, and through 4 in. on the pipe diameter scale; where it crosses the loss of head scale will give the desired value, 18 ft. for new pipe.

The right-hand diameter scale is for new and smooth pipes, the left-hand scale for old or rough pipes. These values apply to straight lengths of pipes. Where fittings or valves are introduced extra loss of head will result. The simplest way to bring in this loss is to introduce the equivalent length of straight pipe which from experiments is practically as follows:

Added Loss of Head in Fittings and Valves

Kind—	Added Length in Pipe Diameters
Bends, radius = pipe diameter	20
Bends, radius = 2 to 8 diameters	10
Elbow, short turn 90 deg	30
Elbow, short turn 45 deg	6
Tees, short turn 90 deg	60
Gate valves	6
Globe valves	60
Angle valves	90

From these figures it will be evident that careful planning to reduce elbows and use long radius bends will be well repaid by the saving in power, which will save fuel.

To determine the actual power loss due to friction of piping, multiply the loss of head in feet by the weight of water moved per unit of time as per second or per minute. Assuming the loss of head to be 3 ft. and the number of pounds of water moved each minute 1100, the actual energy loss would be equal to the product of 3 and 1100 or 3300 ft. lb. This is equivalent to 1/10 hp.

STEAM LINE LOSSES

LOSSES occurring in steam lines are primarily due to leakage, friction and radiation. Those due to radiation have already been discussed.

According to Carpenter, the drop in pressure P, in pounds per square inch of steam flowing through a pipe

d inches in diameter and L feet in length may be calculated by the use of the following formula:

$$P = 0.000,130,6 \frac{W^2 L \left(1 + \frac{3.6}{d}\right)}{yd^5}$$

where W is the weight of steam in pounds per minute and y is the mean density in pounds per cubic foot.

Considerable calculation may, however, be eliminated by the use of the chart, Fig. 2. Assume the passage of 20 lb. of steam per minute through 500 ft. of 3-in. pipe, pressure 80 lb. per square inch and that it is desired to determine the drop in pressure. Trace as indicated from "20 lb." at the right of the chart, to the "80 lb. pressure" ordinate, then parallel to the diagonal lines to the 3-in. diameter ordinate and drop from this point to "0.3 lb. loss of pressure per 100 ft." For a 500-ft. length the total pressure drop will therefore, according to this chart, be equal to 0.3 times 5 or 1.5 lb.

Actual energy loss due to friction of steam piping is proportioned to the pressure drop. No definite relation can, however, be established because of the variable factors involved such as the rate of flow of the steam, the pressure, the quality if saturated and the degree of superheat.

Testing for Friction Losses

Tests can be made to determine the percentage of power absorbed by friction of line and counter shafting as follows: Take indicator cards on the engine at intervals during the day while machines are in full operation, and again at noon and at night when the machines are not in use and the belts on loose pulleys. By averaging the indicated horsepower when running under full load and again when running light and deducting the latter from the former, an accurate record of the power absorbed by friction can be obtained.

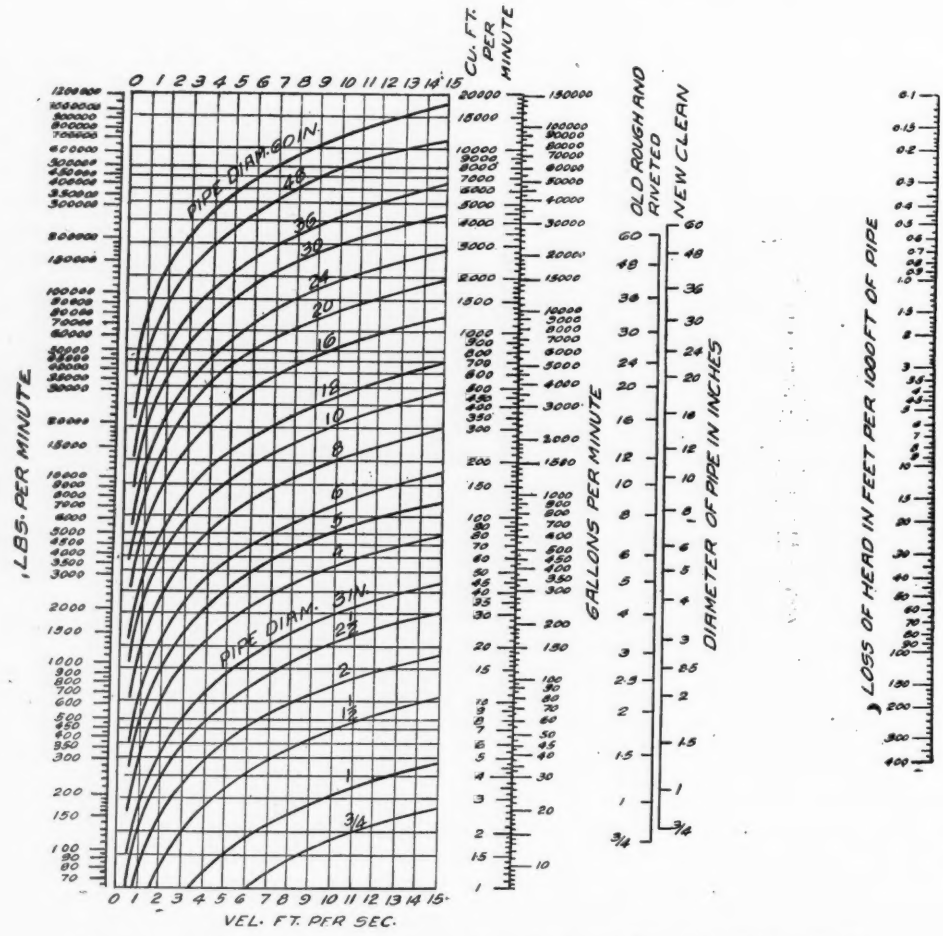

LBS. PER MINUTE
CU. FT. PER MINUTE
GALLONS PER MINUTE
OLD ROUGH AND RIVETED
NEW CLEAN
DIAMETER OF PIPE IN INCHES
LOSS OF HEAD IN FEET PER 100 FT. OF PIPE
PIPE DIAM. 60 IN.
PIPE DIAM. 3 IN.
VEL. FT. PER SEC.

FIG. 1. CHART OF FLOW OF WATER IN PIPES AND LOSS OF HEAD BY FRICTION

In the case of motor drives, the input in electrical energy when loaded and when idle must be compared. The instruments to be used to take readings are, in the case of direct-current motors a voltmeter and an ammeter. Connect these instruments in the manner shown in Fig. 3. Care must be taken that the ammeter is of sufficient capacity to measure the full-load current of the motor. The product of the voltmeter reading and the ammeter reading divided by 746 will give the horsepower input of the motor.

In the case of alternating-current motors, indicating wattmeters should be used. Test results indicate shaft losses ranging from 15 to 70 per cent of the total power transmitted with an average for various industries of about 38 per cent.

It is the opinion of Prof. J. J. Flather, based on tests, that a reasonable per cent of loss in shafting, for average light work with shafting in fair condition, is from 30 to 40 per cent of the total power expended, while for heavy work this loss will probably average from 40 to 50 per cent, assuming of course that the shafting is in fair alinement and properly lubricated, with hangers sufficiently close to each other to prevent undue deflections under working conditions; also that the belting is not unnecessarily tight. Departure from these conditions will increase or decrease the assumed friction loss, depending upon the degree of perfection attained in erection and maintenance of the shafting.

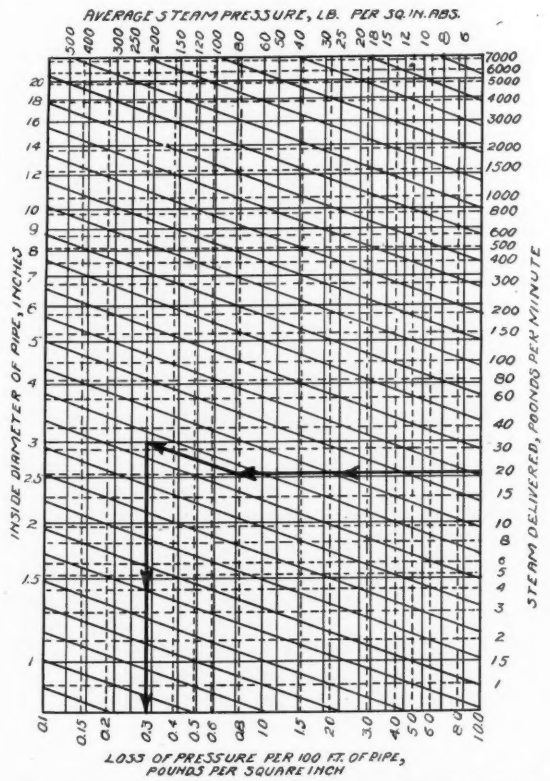

AVERAGE STEAM PRESSURE, LB. PER SQ. IN. ABS.
INSIDE DIAMETER OF PIPE, INCHES
STEAM DELIVERED, POUNDS PER MINUTE
LOSS OF PRESSURE PER 100 FT. OF PIPE, POUNDS PER SQUARE INCH

FIG. 2. CHART FOR DETERMINING LOSS OF STEAM PRESSURE PER 100 FT. OF PIPE, POUNDS PER SQUARE INCH

If excessive loss is found to exist, means should be employed to locate the section or sections responsible. This may be best done by testing separately the shafting on the various floors or in the individual departments, electric motor drive being preferable for this purpose.

Causes of excessive power losses in ordinary line shafting can be directly traced to one or more of four reasons: Overloading of bearings, poor alinement, bent shafting and poor lubrication. The overloading of bearings may be due to bearings being too short, not enough bearings or overtight belts.

Pressure per square inch on the projected area of the shaft in the bearing has been found in good practice to range from 400 to 800 lb. depending upon the nature of the service rendered. In general transmission, this has solved itself into certain ratios of length of bearing to the diameter of the shaft. For shafts under 100 r.p.m., 2.75 times the shaft diameter; for 100 to 300 r.p.m., three times the diameter.

The proper distance between bearings is governed by the shaft deflection which should not exceed 0.001 in. per foot of length.

For ordinary line shaft work, it is sometimes necessary to place pulleys at various points along the shaft without reference to the bearings. The general rule for line shafts is to place the bearings 8 ft. apart.

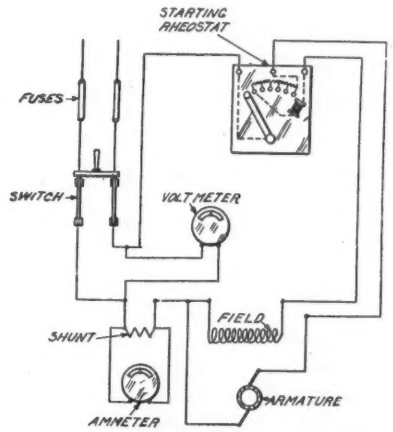


FIG. 3. ELECTRICAL CONNECTIONS FOR TESTING SHAFT FRICTION BY MOTOR

Expressed as a rule, where shafting is used for transmission alone, distance D in feet between bearings is taken as the cube root of the product of 720 times the diameter, d, in inches, squared ($D = \sqrt[3]{720\,d^2}$). When the shaft carries a number of pulleys placed at various points between bearings, distance D′ is equal to the cube root of 140 times the diameter squared ($D' = \sqrt[3]{140\,d^2}$).

Methods adopted for establishing a line of shafting or correcting the alinement must be worked out to suit the individual case. A method commonly employed is to stretch a wire to which the line of shafting can be compared. This reference line is usually placed directly over the shaft, its level being accurately determined by means of a spirit level and its position in regard to the machinery and building carefully adjusted.

Having the line accurately placed, measurements are taken both horizontally and vertically from the line to the shafting, and by means of the screw-adjustment in the shafting supports, accurate alinement can be secured. Vertical alinement can be checked by means of a leveling rod and carpenter's level while the horizontal line may be checked by hanging plumb bobs from various points along the shaft.

In taking the level of a shaft, a straightedge should be provided which will extend from one bearing to the next and the level applied to the straightedge, not to the shaft.

Cutting Out Idle Lines

In the distribution of power by line shafting, economy can be obtained by providing for flexibility by the

use of friction clutches or clutch couplings to cut off line shafts running idle or not in use at all times. Proper points to install clutch couplings or friction clutches are where machines are idle a good part of the time and where light and periodic loads are carried.

Electric Energy Losses

Faulty design, overloading, the use of conductors, switches, etc., of insufficient carrying capacity, loose connections, defective joints, grounds due to poor insulation and grounds due to defective apparatus may be enumerated as some of the causes contributing to excessive and unwarranted losses in electric distribution systems.

Wiring Calculations

When at a temperature of 75 deg. F., a 1-ft. length of commercial copper wire with a cross-sectional area

TABLE II. SAFE CARRYING CAPACITIES OF VARIOUS SIZES OF CONDUCTORS WITH RUBBER AND OTHER INSULATION

B. & S. Gage Number	Diam. of Solid Wire In Mils	Area in Circular Mils	Rubber Insulation Amperes	Other Insulation Amperes
18....	40.3....	1,624....	3....	5
16....	50.8....	2,583....	6....	10
14....	64.1....	4,107....	15....	20
12....	80.8....	6,530....	20....	25
10....	101.9....	10,380....	25....	30
8....	128.5....	16,510....	35....	50
6....	162.0....	26,250....	50....	70
5....	181.9....	33,100....	55....	80
4....	204.3....	41,470....	70....	90
3....	229.4....	52,630....	80....	100
2....	257.6....	66,370....	90....	125
1....	289.3....	83,690....	100....	150
0....	325.	105,500....	125....	200
00....	364.8....	133,100....	150....	225
000....	409.6....	167,800....	175....	275
		200,000....	200....	300
0000....	460.	211,600....	225....	325
		250,000....	240....	350
		300,000....	275....	400
		350,000....	300....	450
		400,000....	325....	500
		500,000....	400....	600
		600,000....	450....	680
		700,000....	500....	760
		800,000....	550....	840
		900,000....	600....	920
		1,000,000....	650....	1,000

of one circular mil has a resistance of 10.8 ohms. It is therefore evident, remembering that the resistance of a conductor varies directly as its length and inversely as its cross-sectional area, that the resistance of a conductor of such wire may be readily determined by dividing the product of 10.8 and its length in feet, by its cross-sectional area in circular mils. Or expressed as a formula, we have

$$R = (10.8 \times L) \div C.M. \ldots\ldots (1)$$

where R is the resistance in ohms, L the length of the conductor in feet and C.M. the cross-sectional area in circular mils.

The product of the resistance of a conductor in ohms and the current flow in amperes gives the voltage drop. Multiplying, therefore, each side of the above equation by I, the current flow in amperes, we have

$$IR = I\,(10.8 \times L) \div C.M. \ldots\ldots (2)$$

or

$$e = I\,(10.8 \times L) \div C.M. \ldots\ldots (3)$$

in which e is the drop in volts.

Therefore, with a knowledge of the maximum amount of current in amperes to be carried, the length of the conductors in feet and the allowable voltage drop, transposition of formula (3) will provide a ready means for the determination of conductor size for any two-wire direct-current circuit. We then have

$$C.M. = I\,(10.8 \times L) \div e \ldots\ldots (4)$$

Should it be preferable to use the length of conductor

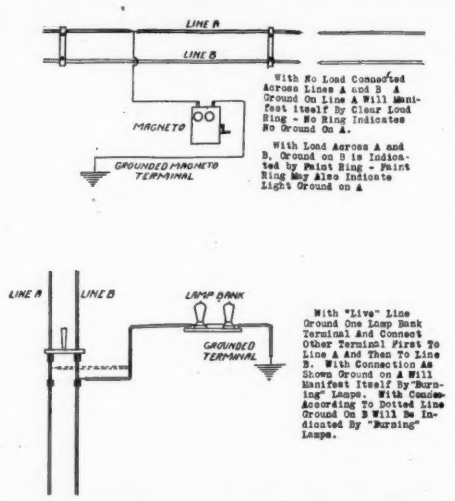

LINE A
LINE B
With No Load Connected Across Lines A and B A Ground On Line A Will Manifest itself By Clear Load Ring - No Ring Indicates No Ground On A.
MAGNETO
GROUNDED MAGNETO TERMINAL
With Load Across A and B, Ground on B is Indicated by Faint Ring - Faint Ring May Also Indicate Light Ground on A
LINE A
LINE B
LAMP BANK
GROUNDED TERMINAL
With "Live" Line Ground One Lamp Bank Terminal And Connect Other Terminal First To Line A And Then To Line B. With Connection As Shown Ground on A Will Manifest Itself By "Burning" Lamps. With Connection According To Dotted Line Ground On B Will Be Indicated By "Burning" Lamps.

FIG. 4. SHOWING METHOD OF TESTING FOR GROUNDS BY MEANS OF (A) BELL-RINGING MAGNETO AND (B) LAMP BANK

from the point of energy delivery to the center of load or distribution $L \div 2$ is used instead of L so that formula (4) becomes:

$$C.M. = I\,(10.8 \times L) \div 2e \ldots\ldots (5)$$

For a two-wire circuit, L is twice the transmission distance.

To insure compliance with Code requirements, however, a comparison should be made with a table showing the maximum safe carrying capacity of various sized conductors fitted with rubber and other insulation. Should the size of the conductor as determined by the above formulas be found smaller than that required by the Code, the size specified by the Code should be used.

On lighting circuits a drop of from 1 to 3 per cent of the receiver voltage is allowable, while in motor circuits this may vary from 5 to 10 per cent or even slightly more.

As in practice three-wire direct-current circuits are ordinarily designed under the assumption that the system is balanced, either formula (4) or (5) may be employed to compute the conductor size required for such a system. Due, however, to the fact that two groups of receivers are connected in series, the total drop in voltage is only the sum of the drop in the two outside lines and equal to that occurring in each receiver group used alone.

National Electrical Code specifications require the

neutral line to be of the same size as that of each of the outside conductors.

For a two-wire circuit, we have found the conductor size in circular mils [formula (5)] equal to

$$I\ (10.8 \times L) \div 2e.$$

By allowing a voltage drop in a three-wire system twice that of a two-wire system of equivalent capacity, we shall have the same per cent loss of energy delivered and

$$C.M. = I\ (10.8 \times L)\ 2 \times 2e$$

or

$$C.M. = I\ (10.8 \times L) \div 4e \ldots . (6)$$

thus indicating that in a three-wire system each of the outside conductors has a sectional area of but half that of each of those of a two-wire system or in other words, but 50 per cent of the copper is required, that would be under the assumption that no neutral is employed. With a neutral conductor, however, which, as stated, is to be of the same size as each of the outside lines, another 50 per cent of the copper of the outside lines of the three-wire system or 25 per cent of the total copper of an equivalent two-wire system, is required. It is thus evident that as each of the two outside conductors of a three-wire system constitutes but 25 per cent of the total copper of a two-wire system and as three conductors of like size are employed in three-wire work the total

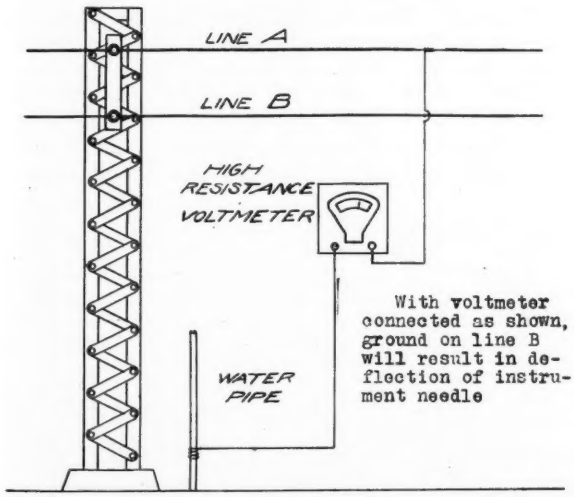

LINE A
LINE B
HIGH RESISTANCE VOLTMETER
WATER PIPE
With voltmeter connected as shown, ground on line B will result in deflection of instrument needle

FIG. 5. METHOD OF TESTING FOR GROUNDS BY MEANS OF VOLTMETER

copper of a three-wire system is but three times 25, or 75 per cent of that of an equivalent two-wire system.

Loss of Power

In any electrical conductor regardless of the material of which it is composed, a voltage drop, e, is bound to occur. This drop is dependent in value upon the resistance of the conductor in ohms and the current flow in amperes and may readily be represented by the formula $e = R\ I$ wherein R is the resistance and I the current. The total power in an electric circuit expressed in watts is equal to the product of the applied voltage E and the current flow I, or E I. That lost in overcoming resistance is equal to the product of e and I and as e as above shown is equal to R I, the loss in watts may be expressed by the product of I and R I, or $R\ I^2$.

Again, we have found that e [refer to formula (3)] is equal to $I\ (10.8 \times L) \div C.M.$, so that we may also express the loss as

$$e\ I = I^2(10.8 \times L) \div C.M. \ldots . (7)$$

obtained by multiplying both sides of the equation of formula (3) by I.

Alternating-Current Calculations

In single-phase work where reactance may be neglected and the power factor is unity, the required conductor size is calculated by means of the formula employed for two-wire direct-current circuits. Where, however, the power factor is other than unity the value of the current flow must be first determined which for all practical purposes may be done by the employment of the following formula:

$$I_1 = (kw. \times 1000) \div (E \times p.f.) \ldots . (8)$$

where I_1 is the current flow in amperes, kw. the kilowatt load, E the line voltage and p.f. the power factor

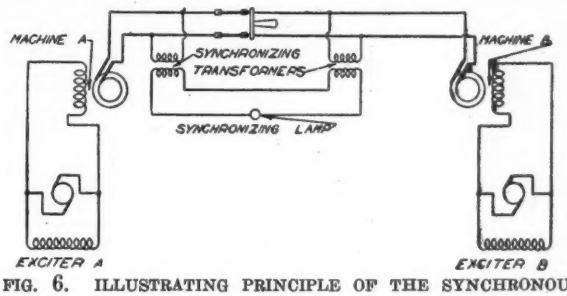


FIG. 6. ILLUSTRATING PRINCIPLE OF THE SYNCHRONOUS MOTOR

expressed as a decimal. The size of conductor to use is then determined by substituting this value of I_1 in formula (5).

For two-phase four-wire balanced circuits the current flow through each of the four conductors is equal to

$$I_2 = \frac{kw. \times 1000}{2\ E \times p.f.} = \frac{kw. \times 500}{E \times p.f.} \ldots . (9)$$

The value of the current I_2 thus obtained is then used as before to determine the size of the conductor needed.

In any three-phase three-wire circuit the power, in kilowatts, is equal to $\sqrt{3}\ E\ I_3\ p.f. \div 1000$ where E is the voltage across any two conductors, I_3 the current flow through any one conductor and p.f. as before the power factor expressed as a decimal. I_3 the value of the current flow through any conductor may be obtained by dividing the value of the power in watts (or kw. $\times$ 1000) by the product of $\sqrt{3}$ (which is 1.73), E and p.f. or

$$I_3 = (kw. \times 1000) \div (E \times p.f. \times 1.73)$$
$$= (kw. \times 580) \div (E \times p.f.) \ldots . (10)$$

The required size of conductors in circular mils may then be calculated by the use of the following formula:

$$C.M. = I_3 \times 10.8 \times L \times 1.73 \div e \ldots . (11)$$

Formula (7) may be used to determine the power loss in any single-phase circuit. For a two-phase four-wire circuit assuming balanced loads the power loss in watts is equal to

$$2\ I_2^2\ (10.8 \times L) \div C.M. \ldots . (13)$$

Detecting Grounds

Electric machine grounds may be readily detected by disconnecting all of the windings and subjecting each

to a ground test, using for this purpose either a bell-ringing magneto or a lamp bank as shown at A and B. Fig. 4. Whenever a defective element is found it should be removed and reinsulated or rewound if necessary.

For the detection of line grounds, connect one terminal of a high reading voltmeter to some positively grounded object as a water hydrant or pipe or some structural steel member of the building and the other to each of the lines of the circuit under test. If, in the case of a two-wire system, the instrument shows a deflection of the pointer, the line not connected to the meter is the one grounded. Where, however, a three-wire system is under test, the ungrounded voltmeter terminal is connected successively to each of the line wires; when connected to the ground conductor, no deflection will occur.

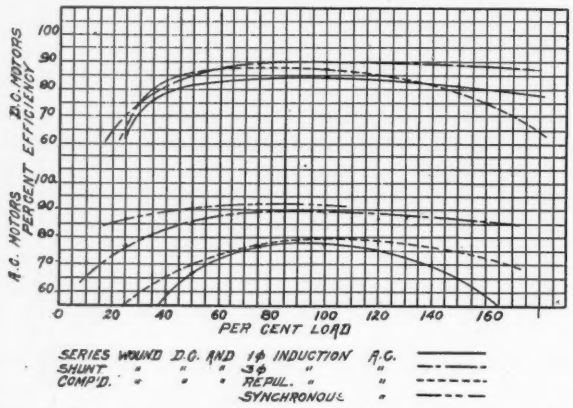


FIG. 7. COMPARATIVE EFFICIENCIES OF VARIOUS TYPES OF MOTORS

Line grounds may also be detected by means of the bell ringing magneto although this should not be employed in circuits known to be "alive." With this connected as shown in Fig. 4 the grounded conductor or conductors will ring clear and loud while with current consuming apparatus connected across the lines the ungrounded line will tend to "ring" faint and indistinct.

Effects of Low Power Factor

An alternating-current generator may be delivering practically all of the current for which its windings are designed while the actual energy output is but a fraction of the machine's rated capacity if current and electromotive force are not in phase. The effect of this is excessive copper loss in both machine windings and the conductors comprising the distribution system.

Various means are available for the correction of this condition or, in other words, the raising of the power factor. If low power factor is due to the use of many underloaded induction motors, as is frequently the case, rearrangement of driven machines and change of schedule of manufacturing processes so as to cause these motors to carry loads nearer their capacity rating may improve conditions appreciably. Should this, however, not be the case or the suggested changes not be feasible other means of correction will need to be employed. Over-excited synchronous motors are generally used for this service.

Operation of the synchronous motor which, in reality, is an inverted alternating-current generator, may be understood by reference to Fig. 6, a conventional diagram representing two alternators connected for parallel operation. If, for some reason, the prime mover of machine B fails, not only will the load carried by this unit be thrown onto machine A, but machine B will become a motor and be driven by machine A, thus exemplifying an alternator driving a synchronous motor; hence, any machine usable as an alternating-current generator may be operated as a synchronous motor and vice versa.

As in the case of alternating-current generators, synchronous motors require a separate source of direct current for the excitation of their field windings. Line current taken by a synchronous motor will lead the electromotive force when the exciting current of the motor is greater than normal, or as technically stated, "an over-excited synchronous motor will draw a leading current," thus enabling it to neutralize wholly or in part the lagging effect of an inductive load.

Balancing Action

The fact that a synchronous motor draws a leading current when over-excited and that the value of this leading current is increased with an increase of over-excitation, gives to this type of polyphase machine the capability of restoring a balance to an unbalanced polyphase circuit. When a slightly over-excited motor is connected to the terminals of a balanced or an unbalanced polyphase system, all phases of the motor armature draw a leading current. That phase winding, however, which is connected across the terminals of lower voltage, draws a greater leading current than the other windings, because its over-excitation is relatively higher,

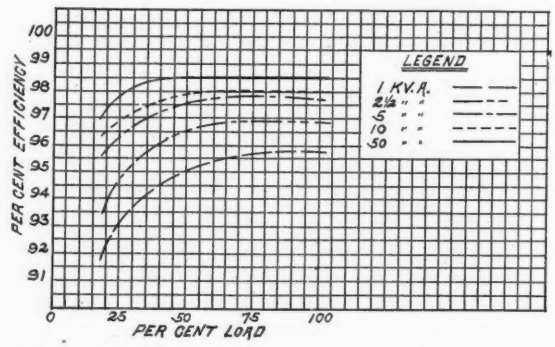


FIG. 8. COMPARATIVE EFFICIENCIES OF VARIOUS SIZES OF TRANSFORMERS

hence the compounding tendency of the leading current is more marked in this phase than in the others, and the voltage thereof is increased. This action tends to balance the circuit, not only in voltage but in current as well, because combinations of leading and lagging currents give reduced resultant currents.

Idle and Underloaded Motors and Transformers

Whether group or individual motor drive should be employed is to a great extent governed by local conditions and as a consequence it is practically impossible to advance any general principle to follow in the selection of a drive for any given case. Large machines, however, and those requiring variable speed drives should preferably be provided with individual motors

while where small and medium size machines are to be served and particularly when near together the group drive will prove the more satisfactory and economical.

Idle and underloaded motors, frequently the result of improper arrangement and operation of the driven machine or machines, contribute largely to the reduced efficiency of the individual motor, to excessive load on generating equipment and distribution lines and in the case of alternating-current systems to low power factor with its detrimental effects. Maximum efficiency of any electric motor is obtainable only by operation at or near full load. Both overloading and underloading as indicated by the curves shown in Fig. 7 cause a motor to work at a lower efficiency than when at rating, and while within certain limits and in the case of certain machines, as series and shunt-wound direct current and three-phase induction type alternating-current motors, the effects of overloading are not serious, practically all motors when carrying loads of 60 per cent of rated capacity or less do so at comparatively low efficiency. Increasing the load on any direct-current machine from 25 per cent of its rating up to 100 per cent will, as indicated, result in an increase of efficiency of from about 60 to approximately 87 per cent. In the case of the three-phase induction motors, the efficiency increase realized by like change in loading will amount to 18 per cent while,

Where direct lighting systems are used, i. e., where there are no reflecting or diffusing surfaces concave upward to invite dirt accumulation, the interval of cleaning should be about as follows:

Characteristic of Location	Interval in Days if Units are Wiped out*	Interval in Days if Units are Thoroughly Washed
Very Dirty	3	5
Dirty	7	10
Average	15	20
Clean	30	40

Where open semi-indirect or totally indirect units are used:

Characteristic of Location	Interval in Days if Units are Wiped out*	Interval in Days if Units are Thoroughly Washed
Dirty	5	7
Average	10	15
Clean	20	30

*Washing every third or fourth interval assumed.

FIG. 9. A SUGGESTED LAMP-CLEANING SCHEDULE

where single-phase machines are employed, this gain may be as great as 30 to 35 per cent.

Redistribution of Load

Where a motor is used to drive a single machine, increase of efficiency may be attained only by operation of the driven machine at or as near full load as possible and by stopping the motor whenever idle for any appreciable length of time. But, with the employment of group drives, a study of existing conditions will many times reveal ways and means by which a more uniform load may be secured. Re-location of motor and re-distribution of load or even minor changes in schedule of manufacturing processes may prove necessary to attain the results desired.

Few manufacturing plants or even departments of such plants operate continuously at full capacity. It is therefore obvious that unless local conditions necessitate the contrary, no single motor should be depended upon for the driving of all of the machinery. Exception to this rule may, of course, be taken in the case of plants normally requiring nearly the rated capacity of the motor with peaks of such magnitude and duration as may be readily handled by the machine without undue heating and serious sparking at the commutator. In the case of direct-current motors, overloading should not exceed 25 per cent of the rated capacity and that for a period of no more than 2 hr. and then only as long as the temperature rise is not in excess of 55 deg. C. (100 deg. F.) above a 40 deg. C. (104 deg. F.) room temperature.

Idle and Underloaded Transformers

Although the actual working efficiency of transformers is high (about 98 per cent for a 10-kv.a. unit)

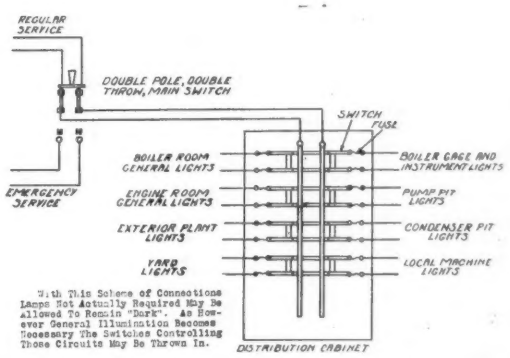

REGULAR SERVICE
DOUBLE POLE, DOUBLE THROW, MAIN SWITCH
SWITCH
FUSE
BOILER ROOM GENERAL LIGHTS
BOILER GAGE AND INSTRUMENT LIGHTS
EMERGENCY SERVICE
ENGINE ROOM GENERAL LIGHTS
PUMP PIT LIGHTS
EXTERIOR PLANT LIGHTS
CONDENSER PIT LIGHTS
YARD LIGHTS
LOCAL MACHINE LIGHTS
With This Scheme of Connections Lamps Not Actually Required May Be Allowed To Remain "Dark". As However General Illumination Becomes Necessary The Switches Controlling Those Circuits May Be Thrown In.
DISTRIBUTION CABINET

FIG. 10. LAYOUT OF LIGHTING CIRCUITS FOR A SMALL POWER PLANT

when compared with other forms of energy conversion apparatus the so-called all-day or 24-hr. efficiency tends to be low particularly in industrial plants where normal loads are carried during but short periods of time. Let us assume that a 15-kv.a. transformer having an iron or core loss of 500 w. and a copper loss of 500 w. when fully loaded, works at full capacity (and unity power factor) but 8 hr. each day and is without load the remaining 16 hr. The core loss remains constant, so that this for 24 hr. amounts to 24 times 500, or 12,000 w.-hr., while the copper loss is equal to 8 times 500 or 4000 w.-hr. When the transformer is working at rated capacity, that is, is delivering 15,000 w. it is being supplied with $500 + 500 + 15{,}000$ or 16,000 w., an efficiency of 94.8 per cent. It will receive 128,000 w.-hr. for the 8 hr. of full load working. It is, however, receiving during the remaining 16 hr., 16 times 500, or 8000 w.-hr. to compensate for the continuous core loss. The total energy delivered to the transformer during the day is then equal to 128,000 plus 8000 w.-hr. or 136,000 w.-hr., the total output 120,000 w.-hr., so that the all-day efficiency is equal to 120,000 divided by $136{,}000 = 0.882$ or 88.2 per cent. As the number of hours of full-load working is reduced, the all-day efficiency drops likewise until with a 2-hr. working day the efficiency would be 68.4 per cent.

The actual working efficiency of a transformer is also dependent upon its size. As shown in Fig. 8, at full load a 1-kv.a. unit has an efficiency of about 95.7 per cent, while that of a 50-kv.a. transformer is 98.5 per cent.

Idle Lamps

Idle lamps or lamps allowed to remain burning when light is not actually required not only result in a waste of electric energy, but add materially to the maintenance cost of the system by the resulting reduction of the useful life of the lamps. It is, therefore, obvious that when a lamp is usefully employed but 50 per cent of its total life (which in the case of straight side 110 to 250-v. Mazda lamps is about 1000 hr. and round bulb units of like voltage rating is approximately 750 hr.) the overhead charge carried by that particular lamp will be 100 per cent greater than if the unit had been allowed to burn only at such times as the light was really required.

Operating lamps below rated voltage, improper care and maintenance of lamps and reflectors and dirty and dark colored walls and ceilings are also factors conducive

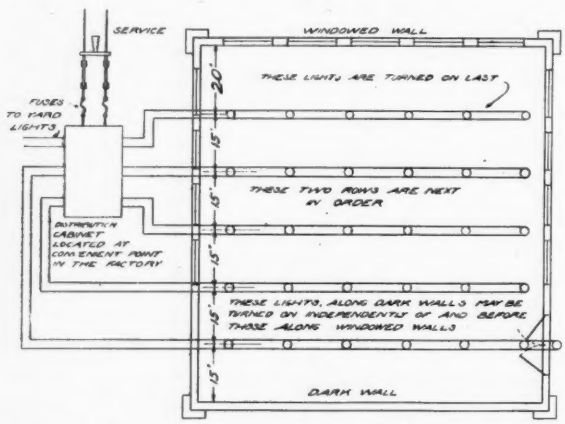


FIG. 11. LAYOUT OF LIGHTING CIRCUITS FOR A SMALL MANUFACTURING PLANT

directly to inadequate illumination and indirectly to waste of energy. Results of tests conducted for the purpose on 150-v. Mazda lamps indicate a 15 per cent loss of light when operating at 5 v. under voltage, 29 per cent loss at 10 v. under voltage and 41 per cent loss at 15 v. under rating. Extreme care should be taken, therefore, not only to maintain the voltage of the system but also to replace broken, burned out and blackened units only with others of correct size and proper voltage rating.

For proper maintenance the lighting system should be placed in charge of some reliable employe given sufficient authority to get the work done. The cleaning schedule to be followed depends to a great extent upon the characteristics of the location and whether the lamps and reflectors are merely wiped with a dry piece of cloth or waste or are thoroughly washed. The National Lamp Works of the General Electric Co. suggests the schedule shown in Fig. 9.

Where Mazda lamps (which today are employed more extensively than any other type of electric lighting unit) are in use it is desirable to finish all ceilings and high side walls in white although a light cream color may be used if for any reason the white is objectionable. For some classes of work, particularly where color values are of little importance but where fine detail discrimination is required, the mercury arc lamp is well adapted. The light given out by the lamp is of a greenish-blue color and is devoid of all red rays.

Eliminating Idle Lamps

Elimination of idle lamps or the securing of a maximum degree of efficiency of a lighting system may be obtained by (1) correct design and construction and by (2) proper care and maintenance. Frequently and particularly in the older systems little consideration was given the arrangement of the lighting units and the scheme of electrical connections employed thus providing not only inadequate and unsatisfactory illumination but also no means for the control of the individual units or group of units so as to render possible the operation of only those actually required. Except for special operations, general overhead lighting is preferable to the use of local units and in order to insure a maximum degree of flexibility of operation and to provide the desired illumination without undue waste of energy, wiring layouts should always be arranged in such a manner as will allow the grouping of those units generally in use at the same time. The diagram of wiring for the lighting system of a small power plant shown in Fig. 10 illustrates this. As indicated, all lamps in dark places, as between and in rear of boilers where few windows are placed, in sumps and pits, should at all times be grouped to allow their use without necessity of burning other lamps such as employed for general illumination. Also, overhead, pilaster bracket and other lamps which may be required for localized service are preferably to be kept separately grouped and controlled by individual switches.

In shops and factories using general overhead lighting, a scheme such as typified in Fig. 11 may be used to advantage. With the arrangement employed the center groups are the first to be lighted to be followed only by the others as may be required by the degree of natural illumination obtainable.

Preferably the operation of any lighting system should be placed in exclusive charge of some responsible individual or individuals as for instance the foreman or foremen or perhaps the man designated to maintain the system. Frequently, the installation of automatic time switches may prove advantageous.

Fuel Wastes Involved by Idle Lamps

Continuous burning of an individual lamp may result in a negligible waste of fuel; but whereas in large plants a considerable number of lamps remain burning when not actually required, due either to carelessness on the part of the employes or faulty arrangement of the electrical wiring system, the annual waste of fuel becomes of vital consequence.

Let us assume that in a medium-sized manufacturing plant an average of fifty 60-w. lamps, installed in passageways, stairways, halls, etc., are allowed to remain

burning uselessly 4 hr. each working day. This would require an expenditure of 3000 w. per hour, 12,000 w.-hr. or 12 kw.-hr. per day and 3600 kw.-hr. per year of 300 working days. Under the further assumption that this represents but 5 per cent of the actual energy of the fuel used, a consumption of 2½ lb. of coal per horsepower hour, 120,000 lb. or 60 tons of coal are actually wasted each year. With coal costing $10 per ton, this would result in a needless annual expense of $600 or the interest at 6 per cent, on an investment of $10,000.

If by re-arrangement of the wiring systems and proper supervision 50 per cent of the waste may be eliminated, a yearly saving of $300 is possible.

Boiler Efficiency and Stack Temperature

By W. F. Schaphorst

TO MEASURE boiler efficiency we are usually told to "find the heat in the steam evaporated by the boiler and divide it by the heat in the coal." In other words, boiler efficiency, like all other efficiencies, is equal to "output" divided by "input."

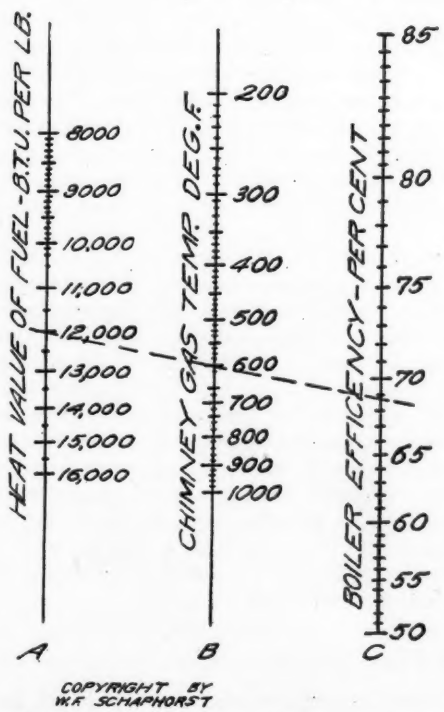


CHART FOR DETERMINING BOILER EFFICIENCY

Why bother, however, about the steam at all if we know the quantity of heat that escapes through the chimney? Can't we conclude that the heat that "doesn't" escape is absorbed by the boiler? To determine the output, then, simply subtract the heat lost up the chimney from the original heat in the coal. On this basis of reasoning, therefore, we get this formula:

$$\frac{\text{(Heat in coal)} - \text{(Heat lost up chimney)}}{\text{(Heat in coal)}} = \text{Boiler efficiency}$$

It is not easy to figure the "exact" amount of heat lost up the chimney; but it can be done with a fair degree of accuracy, if one knows the number of pounds of gases passing up the chimney in a given time. The trouble is, the quantity varies with the different coals and with the different firemen. A first-class fireman with a CO_2 machine can regulate the flow of air until it is "just about right." Perhaps he will use 18 lb. of air per pound of coal—perhaps more; 18 lb. is usually considered a "good" figure.

Rather than be guided by mere theory, though, the writer studied the averages of a number of authoritative tests where the boiler efficiency varied from a trifle over 60 per cent to nearly 80 per cent. The heat value of the coal was considered in each case, together with the temperature of the chimney or exit gases. As a result, the formula below was derived, which may be considered a good "rough" formula for computing boiler efficiency, provided the fireman is doing his level best to effect complete combustion. If the fire is poor, so that the gases contain a large per cent of CO, the formula naturally will not hold. This is the formula:

$$100 - \frac{625T}{H} = \text{boiler efficiency in per cent.}$$

where H = heat value of dry coal in B.t.u. per pound;
T = temperature of the chimney gases in degrees F.

For example, what is the approximate boiler efficiency where the heat value of the coal is 12,000 B.t.u. per pound, and the chimney gas temperature is 600 deg. F.

Substituting the formula, we get:

$$100 - \frac{625 \times 600}{12{,}000} =$$

$$100 - 31.2 = 68.8 \text{ per cent.}$$

The accompanying chart will enable the reader to find the approximate efficiency of a boiler without doing any calculating. Simply stretch a thread across the chart or run a straightedge through the heat value of the fuel, and the chimney gas temperature and the boiler efficiency will be found in column C. The dotted line drawn across this chart shows how the foregoing problem is solved. The line runs through the 12,000 B.t.u. and the 600 deg. F. in columns A and B respectively, and in column C shows the boiler efficiency to be 68.8 per cent.

The chart will be found of further value for showing how important it is, always, to maintain as low a temperature in the chimney as possible. Thus, if you have a coal whose heat value is 12,000 B.t.u, swing a straight line about that point (column A) as a pivot. If you can reduce the temperature of the chimney gas 100 deg. the boiler efficiency will be found to be approximately 74 per cent, or an increase of about 5 per cent. So much coal is wasted up chimneys at the present time, in spite of our recent experiences, that it is hoped a study of this chart will clearly show the seriousness of high exit gas temperature.

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Fuel to Burn

But how are we burning it? And how are we utilizing the energy from this precious store, which once used can never be replaced?

In 1920, we produced and burned some 600,000,000 short tons of coal, and competent authorities state that we could have saved 100,000,000 tons of this by applying engineering principles that are well known and well proved. That means that we have wasted half a billion dollars worth of coal in a year. Not very good burning.

We can do better. During the war, with only four months of experience and the program working in 25 states, saving was made, simply by enforcement of simple rules, without change of equipment, at the rate of 25,000,000 tons a year. Many plants showed a saving of 10 and 20 per cent of fuel used. From this experience it is evident that the estimate of 100,000,000 tons wasted is conservative.

As to the use of energy, figures on page 1 give relative amounts for various purposes. The largest, 67 per cent, goes for making steam on land, railroads and industries. Is the steam used efficiently?

Every engineer knows of prime movers working inefficiently, too big or too small for the load, carelessly operated, exhaust wasted. And beyond the prime mover we have wasteful transmission, badly designed drives and heedless waste in operating machinery.

Coal resources seem inexhaustible when the total amount is considered; but we are approaching the end of the best coal and the most easily mined veins. Then will come poorer coal and higher costs. For petroleum resources, the end is in sight. All authorities agree that we cannot afford to use oil for steam making; it must be conserved for purposes where coal cannot be used. When so used, it should be conserved in every possible way.

Various methods are proposed for furthering the efficient use of fuels. Supervision by government of production, preparation and use; better education of all who deal with fuels, with certificates for those who reach proficiency in knowledge and in performance; processes of distillation by which all elements in fuels may be utilized to the best advantage;—these are suggestions for a general program. Meantime, it is up to the man in the plant to realize the need for saving, both as a matter of reduced present cost and of safeguarding the future; then to go after his own particular problem, "I have fuel to burn. How am I burning it? And how am I utilizing the energy that I am drawing from the world's irreplaceable stock?"

Shall They Starve?

Herbert Hoover, foremost engineer-citizen, knows the conditions in Central Europe intimately. He states that unless we come to the rescue, over three million children there will starve this winter, and urges that the people of the United States, for humanity's sake, meet the emergency. To save one child $10 is needed. It is an individual question for every person whether, to save the life of one little child, he will forego pleasures and luxuries—even make some sacrifice of what seem like necessities. If everybody helps, the amount required

from each one will be small. Some, of course, can do little or nothing, and others must make up for it. Quick decision on what you will do is important, and immediate action. The best way is to send your contribution to your local organization of the American Red Cross, stating that it is for the children of Europe. You can specify for what country it is to be used if you so wish.

For those who do not know where to reach their Red Cross branch, Power Plant Engineering will act as medium to receive and forward contributions. Saving these children is one of the greatest services we can render to Europe, to the world, and to the Christ who loved little children. What better way to start the new year right?

Off Duty

A salesman for a fireproof vault concern not long ago asked a manufacturer of electric motors what he considered the most valuable things in his factory.

"Our jigs and dies," replied the manufacturer without hesitation. "Almost anything else in this factory could be replaced in a short time, but the fixtures and dies would take months to reproduce."

The manufacturer was entirely correct in his statement. Standards and patterns are always valuable. They serve as a standard from which other things are made. The more fundamental any standard becomes, the greater is its value.

As an example, one of the most valuable and most carefully guarded things in existence is the standard meter at Paris. This is in the form of an iridio-platinum bar having two fine lines inscribed upon its surface. The distance between these lines when the bar is kept at a constant temperature of zero degrees, C., represents the international standard meter. This bar is kept in an underground vault at Paris and is only taken out when it becomes necessary to compare another meter bar with it.

This meter is the only unit of metric extension by which all other metric measures of extension—whether linear, surface or solid—are ascertained.

If this standard meter were destroyed, accidentally or otherwise, how could it be replaced? There would be no other unit by which it could be made up because all sub-standards were originally constructed by comparison with the standard.

"Well," somebody will say, "is not the meter supposed to be the one ten-millionth part of the distance between the equator and the North Pole as measured on the earth's surface? Can't they reconstruct the meter from this measurement?"

To be sure, that is exactly what the meter was intended to be, one ten-millionth part of the distance between the equator and the pole, but long after the standard meter had been agreed upon, constructed, and in use, it was discovered that the distance between the equator and the poles had been determined incorrectly and, as a consequence, the meter was wrong. It remained only an arbitrary unit of length.

Furthermore, even though the meter were correct with reference to the measurement of the earth's surface as stated above, have we any reason to believe that this standard of reference is unchangeable? None whatever. The earth's crust is constantly undergoing changes and while they may be slight, in time they may cause an appreciable difference in the earth's size. Indeed no, the earth's size was a poor standard of reference for length.

If that is the case, then, what have we that is absolutely unchangeable—something, that no matter what happened, we could always reproduce and thus use for our standard of length?

Until a few years ago, we could not answer this question. Today, the answer is, light waves. It has been shown that by the aid of light waves, we will always be able to reproduce the meter, the yard, or any other standard of length.

The story is only one of the many in which the results of pure scientific research lay down the basic principles on which we work out present day practical problems. When the velocity of propagation of light waves was determined by scientific reasoning and experimentation of the most refined nature, the process of solving the problems remained for a long time in the domain of the exact sciences as a masterpiece of the human mind.

But who of us dreamed to what an utilitarian purpose these light waves would be made subservient? It was Michelson that carried them into the workshop and gave us a value for the International meter in terms of light waves that will remain absolutely unalterable as long as this old world moves in the ether of the universe. And so, today, we know that our standard meter, measured in terms of the red ray of the spectrum of cadmium equals 1,553,163.5 in air at 15 deg. C. and at normal atmospheric pressure.

These waves so short and of such tremendous velocity that in one second 465 trillion impinge upon the retina of the eye, determine the units of length with unerring precision.

Power Plant Slogans

Keep and Analyze Operating Records in Every Power Plant.
Develop Water Power Sites.
Promote Health and Safety in Power Plants.
Handle Coal and Ashes Mechanically.
Employ Engineers for Engineering Work.

Acknowledgement

In the preparation of this issue of Power Plant Engineering it has been manifestly impracticable to give all sources from which the information was gathered for the reason that the data collected have been so interwoven as to represent a compilation from many papers presented before engineering societies, government bulletins, publications of technical schools and colleges, books by engineering authorities and information secured from various manufacturers. In many cases, however, the source of the information is given in the text and to all who have made the presentation of this issue possible we wish in this manner to make public acknowledgement of the co-operation and courtesies which have been extended us.

News Notes

THE STAR BRASS WORKS, 3114-26 Carroll Ave., Chicago, announces that on and after Jan. 1, 1921, the company name will be changed to Binks Spray Equipment Co. Such change of name has been made to conform more nearly with the nature of the products manufactured. Simultaneously announcement is also made of the completion of a new plant and office extension on the west wing of the old plant in which provisions are made for new sales rooms, testing laboratories, and greatly increased manufacturing facilities on the first floor, with new offices and drafting rooms on the second floor. The new addition was necessary by reason of the rapid expansion of the business in all lines.

THE OXWELD Acetylene Co. announces the appointment of the Standard Supply & Equipment Co., of New York and Philadelphia, as eastern sales agent. The Standard Supply & Equipment Co. has, besides its New York and Philadelphia establishments, branch houses in New Haven, Hartford, Springfield, Worcester, Pittsburgh, Trenton and Altoona. The company has appointed as manager of its welding and cutting equipment department, George E. Temple, for six years connected with the Prest-O-Lite Co.

FOR THE McKeesport Tin Plate Co.'s new power plant at McKeesport, Pa., S. Discher & Sons, Pittsburgh, Pa., were the consulting engineers in charge of the design and construction work, the power plant equipment being furnished and erected by Floersheim & Co., Pittsburgh, and Crane material used throughout.

THE WHITE CONSTRUCTION Co, New York, has been awarded the contract for constructing a new factory and power house for C. F. Stiefel in East Orange, N. J. The building will be of reinforced concrete construction throughout, and will cost $100,000. Plans and specifications were prepared by W. Wiegand, New York.

THE UNITED ELECTRIC LIGHT AND POWER Co., New York, has awarded the contract for constructing its new Hell Gate power station, according to Brown's Letters, Inc., Construction Reports. The building will be erected at Locust Ave. and East 134th St. from plans and specifications prepared by Thomas E. Murray, Inc., 55 Duane St. The contract for the superstructure has been awarded to the United States Structural Co., 841 Broadway, and the foundation work to the P. J. Carlin Construction Co., 1123 Broadway.

AT CEMENT, Okla., $65,000 has recently been expended for a new electric light plant and a water system. The work is nearly completed.

APPLICATIONS have been filed with the Federal Power Commission up to Nov. 20 for permission to develop plants to a capacity of 7,726,651 hp., 4,790,350 hp. on navigable streams and 2,936,301 hp. on public lands and reservations. This is nearly four times the amount that was expected for the first year.

ONTARIO, CAN., is moving in the direction of municipal ownership of utilities on a large scale. A project subject only to ratification by the Ontario government has been completed for purchase by the province of the Mackenzie power interests in and around Toronto for $32,734,000. This includes all the larger hydraulic developments in the province except the Dominion Power Co.'s plant at Hamilton. Toronto street railways are also excepted.

Trade News

HYCALIBRE, Catalog No. 12, has just been received from Consolidated Belting Co., of Philadelphia, manufacturer of high grade leather belting, straps and leather specialties.

FAST FLEXIBLE Turbo-Coupling is the subject of a new booklet illustrating and explaining the design of the turbo-coupling made by The Bartlett Hayward Co., Baltimore, Md.

SINGLE- AND MULTI-STAGE steam turbines and reduction gears are described and illustrated in Bulletin No. 24 of Moore Steam Turbine Corporation, Wellsville, N. Y.

IN A NEW catalog just received from The L. S. Starrett Co., information is given concerning twenty-one new tools, including a universal protractor, positive fine adjustment, micrometer calipers of various types with improved adjustments, radius gage, and firm joint dividers.

THE M. H. DETRICK Co., 155 East Superior St., Chicago, has recently brought out an eight-page folder showing installations of its arches with Type "E" and Coxe stokers. Layouts with leading makes of boilers are shown. The folder will be found interesting to those having this stoker equipment who want to familiarize themselves with latest types of arch construction.

THE WESTINGHOUSE Electric & Manufacturing Co. has issued Leaflet 1910 which describes and illustrates "Electric Drive for Cotton Openers and Pickers." The different methods of drive are given with a table for calculating the size of motor for group drive. Motors and starting apparatus for this equipment is also described and illustrated.

BULLETIN No. 46,042, from the General Electric Co., exhibits Type H-2 Demand Meter for determining maximum current demand. It is suitably lagged to respond only to loads of appreciable duration and, as it operates approximately in conformity with heating characteristics of apparatus, such as distribution transformers, it gives a fair indication of effective loading, especially with rapid fluctuation or prevalence of low power-factor, current values naturally being measured instead of watts.

The meter is suitable for d.c. or a.c. circuits, and is furnished in 3, 5, 10, 15 and 25 amp., up to 500-v. sizes, series type, and can thus be connected for higher—e.g., 2300-v. circuits when properly insulated and isolated. While not possessing the refinement in accuracy of some of the company's other meters, this simple and inexpensive instrument serves well for studying economically certain characteristics of distribution systems.

THE DEXTER valve reseating machine manufactured by the Leavitt Machine Co., Orange, Mass., is described in a new 48-page catalog and its use illustrated with globe, gate and pump valves.

THE C. & G. COOPER Co., Mt. Vernon, Ohio, have recently issued a 40-page, illustrated booklet, describing their line of horizontal, double-acting, tandem gas engines.

This book is an excellent contribution to the gas engine art and speaks for the high state of development which this type of prime mover has reached today. In addition to a brief description of the Cooper gas engines, the many representative plants using these engines illustrated in this book tell a convincing story of the company's progress in the field. Especial mention is made of the adaptability of gas engines to compressor service in the natural gas trade.

BALL ENGINES, until recently made by the Ball Engine Co., Erie, Pa., are now being built by the Erie Ball Engine Co., Pittsburgh, Pa. The new company was incorporated and this business transferred to Pittsburgh, due to the lack of adequate manufacturing facilities at Erie. A large modern factory especially equipped for engine work and providing means for a greatly increased production is at present in full operation. District agencies which have been handling the sales of Ball engines will be continued without change in their personnel.

THE PUBLIC trustees of the Boston Elevated Railway have petitioned the Legislature for authority to spend $4,421,000 for erection of new repair shops, building of a new power house and of storage yards.

The trustees would spend $3,000,000 for new repair shops at the Everett terminal; $1,421,000 to increase power facilities, and an amount yet to be estimated for a storage yard south of the Forest Hill terminal.

The trustees also again asked that the Legislature authorize the state to buy bonds issued for public service improvements.

"Improvement of service," the trustees said, "is the first duty of a street railway." They also declared that "proper operation of a street railway calls for sufficient cars to carry passengers in reasonable comfort, and for shop facilities to keep those cars in repair."

WORK ON a great water power development for the Finch-Pruyn interests will be commenced within a few weeks at Elk Lake, in one of the wildest sections of the Adirondacks. The plans call for a dam 30 ft. high at the outlet of the lake. About 5 mi. down the stream a great power house of the most modern type is to be erected.

A steel penstock will carry the water from the dam to the power house, in a fall of more than 600 ft. The electric power developed is to be sold to resorts and industrial concerns throughout that section of the mountains. The cost of the development is estimated at $750,000.

A PROJECT to bring coal from the anthracite regions in Pennsylvania to New York through two 14-in. pipes, by water pressure, was given consideration recently by the city docks and health commissioners.

The plan was submitted to Mayor Hylan by Reginald P. Bolton. Mr. Bolton explained that between New York and Scranton, Pa., there is a fall in elevation of about 2000 ft. and that it would be as easy to transport coal in this fashion as water. He claimed 7,000,000 t. of coal could be brought through the pipes every year, which would amply supply the city's needs.

THE CHIEF Engineers' Association of Chicago at the annual election elected Charles J. Lehn, president; Walter D. Periera, vice-president; Clifford Gilmore, recording secretary; Wm. H. Couch, financial secretary, and Charles Langs, treasurer.

J. P. GREENWOOD is now associated with the Smith Gas Engineering Co. of Dayton, Ohio, as Southwestern representative. Through his former position as Texas State President of the N. A. S. E. and years of contact with Southwestern plants, Mr. Greenwood has formed a wide circle of friends.

Southwestern fuels, particularly lignite, are considered ideal for use in gas producers, and Mr. Greenwood will be able to show some startling economies made possible through the use of lignite in generating gas for power, where used with gas engines, or for use as industrial fuel. His headquarters are to be 219 Cotton Exchange Bldg., Dallas, Texas.

IN CONNECTION with its efforts to reduce the number and severity of industrial accidents, the Travelers Insurance Co. recently added another book to its accident-prevention series. This new publication is entitled "Safety in the Machine Shop." It contains 188 pages, 6 by 9 in., and is bound in paper covers. It is probably the most elaborate discussion yet published on the various phases of the safety problem as encountered in machine-shop practice.

The book is divided into 14 sections, the first of which sketches the development of the machine shop from the time such an establishment consisted of the proprietor and one or two assistants, up to the present-day shop employing thousands of persons.

In the remaining sections, the safety problems that arise in the modern shop are discussed in detail and careful consideration is given to cranes, lathes, automatic machines, grinding apparatus and other machine-shop equipment. In addition to the discussion of safeguarding and safe operating methods, subjects indirectly related to accident prevention are considered. One section treats of "Infection from Cutting Oils" and another deals with the subject of proper illumination and its bearing on the accident prevention problem.

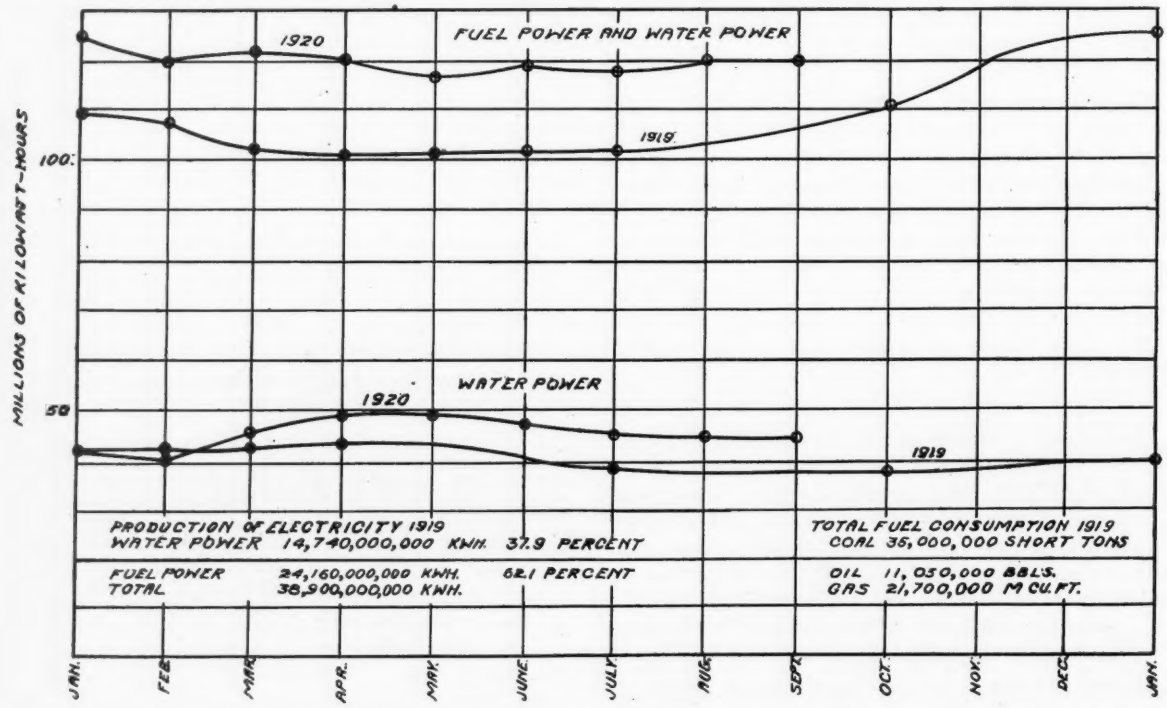
These and other special features will undoubtedly be of interest to machine-shop proprietors and to other persons concerned in accident-prevention work. "Safety in the Machine Shop" will be sent without charge to those making requests for it to the Supply Department, the Travelers Insurance Co., Hartford, Conn.

Electric Power Production

QUANTITIES in the accompanying chart are based on returns received by the U. S. Geological Survey from about 3000 power plants of 100-kw. capacity, or more, engaged in public service, including central stations, electric railways, and certain other plants which contribute to the public supply. The capacity of plants submitting reports of their operations is about 94 per cent of the capacity of all plants listed. As shown by the accompanying curves, the average daily production of electricity in kilowatt-hours by public utility plants for the nine months was as follows: January, 124,700,000; February, 119,800,000; March, 120,700,000; April, 119,100,000 May, 115,600,000; June, 118,800,000 July, 117,000,000; August, 119,700,000, and September, 120,200,000. The proportion of each monthly total produced by water power is 33, 33, 38, 41, 42, 40, 38, 37, and 37 per cent, respectively.

The total output for the nine-month period—January to September, 1919,—was 28,341,000,000 kw.-hr.; for the same period in 1920, the output was 32,739,000,000 kw.-hr., an increase of 15.5 per cent.

The amount of fuels consumed by public utility plants in generating electricity from January to September, 1920, is as follows: Coal, 27.7 million short tons; fuel oil, 9.9 million barrels, and gas, 18.2 billion cubic feet.



AVERAGE DAILY PRODUCTION OF ELECTRICITY BY PUBLIC UTILITY PLANTS IN THE UNITED STATES. WATER POWER AND FUEL POWER DURING 1919 AND 1920

THE INABILITY to make decisions is the greatest human weakness. Wishing for things is a destructive habit. It breeds laziness. People find it so much easier to sigh for the things they want than to go out and fight for them.

Plea for Thrift and Conservation

By L. P. Breckenridge Before the Annual Meeting of the American Society of Mechanical Engineers

THE DIFFICULTY of securing a supply of coal, coupled with the high price paid for it, has in itself brought about a desire to exercise all possible care in its use. The public at large more and more realizes the need of co-operation to secure conservation in some large way. It is in connection with the plan of "Co-operation for Conservation" rather than on "Individual Thrift" that the writer sees the most promising chance for initial success. Especially is this true as a wise first step. Individual thrift should always be practiced, but the large savings of fuel that could be made by co-operation are way beyond anything that could be expected from individual effort. The suggestions for coal conservation which follow are not new—some of them are already begun—but it is only when all of them are fully realized that we shall be able to feel that we are really making satisfactory progress in preventing waste of fuel, as well as waste in labor and capital, which are required to produce and transport fuel.

How to Prevent Waste of Coal

1. Extend as rapidly as possible improved methods of mining coal. Under present conditions, one-third the bituminous and one-half the anthracite coal is left in the mine under such conditions that recovery is practically impossible.

2. Extend improved methods of "preparation" of coal at the mines. A premium might well be allowed

for well prepared coal, or a penalty imposed for impure coal.

3. Reduce the hazards of coal mining. For every 1,000,000 tons of coal mined there are between four and five fatalities.

4. Operate the mines a maximum number of days each year. Mines are operated from 200 to 240 days in one year. Lost time is due to three principal causes: (a) Shortage of cars, (b) shortage of labor or strikes, and (c) mine disability.

5. Utilize a larger amount of the mine waste. Briquetted fuel, pulverized fuel and electricity from mine waste; all are possible of successful development.

6. Increase the use of by-product coke ovens. The by-products wasted by beehive coking are equal to fully 600 lb. of coal per ton of coke produced. Increase the use of domestic coke from the local gas plant. This should tend to keep down the price of gas—and coke is a clean and economical domestic fuel.

7. Extend the use of blast furnace gas for power generation. Much progress has recently been made. It will require co-operative effort to utilize fully the power which might be made from blast furnace gas.

8. Extend the use of the gas producer, the gas engine and the heavy oil engine, for power generation, more especially where electrical energy is not available. Develop the lignite fields—by power from gas producers—and briquetted fuel for domestic use.

9. Extend waterpower development. Hydroelectric power often combined with steam power offers large possibilities for saving coal. It will require comprehensive expert study before any new development can be undertaken or satisfactory financial returns may not be possible. (It will be noted that the above mine suggestions relate to savings which are not concerned with burning coal for making steam or heating homes.)

10. Extend very generally the best known performance of locomotives. The better locomotives of 1920 use only two-thirds of the coal required 20 yr. ago to do the same work. Much saving should be expected in the operation of steam locomotives. Electrification will save coal where water power is conveniently available. Instructions to firemen should be given and followed up even more carefully than in the past.

11. Encourage the tendency of the small industrial plant to purchase its power. The best coal is often sent to the small plant. Small plants, like individuals, should be examined by experts and all reasonable effort made to conserve fuel. Correct equipment and correct methods of operation would save 20-25 per cent of the coal used in industrial plants. It is the coal saved by the industries that will set free transportation facilities sorely needed for other purposes than hauling coal. One-third the railroad tonnage is coal.

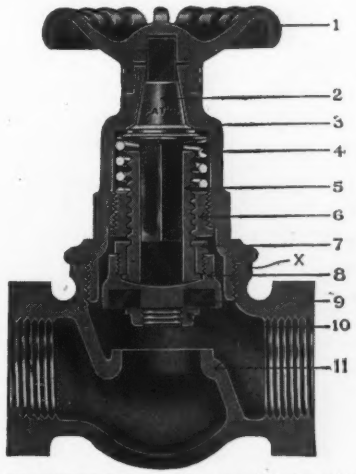
12. Furnish homes and public buildings with correct and simple instructions for operating the furnace, heating boiler and stove. This involves using fuel with suitable equipment for burning it. This should result in saving from 10 to 15 per cent of the domestic coal consumed.

13. Extend the custom of coal storage. The facts relating to this important practice are now available. Coal may be safely stored and the "load curve" on the mining industry may be much improved. The coal should be stored at or near its point of consumption.

14. Extend electrification. The full use of electrical energy offers the most promising means of saving coal. Conservation by co-operation of water power, steam power and electricity opens up large possibilities for saving coal, capital and labor. This is contemplated by the super-power plan now being investigated by the Department of the Interior (U. S. G. S.) and a report is in preparation by an engineering staff which will set forth the facts as to: (a) Needs for super-power, (b) characteristics of an installation, (c) location of suitable super-power lines, (d) estimated costs, (e) estimated economies and other details.

A New Packless Valve

A NEW packless valve has made its appearance on the valve market that is worthy of some note. The drawing is a section of the valve; 1, hand wheel; 2, stem; 3, bonnet; 4, spring; 5, threaded stem insert; 6, threaded stem nut; 7, lock nut; 8, disc holder; 9, disc; 10, disc nut; 11, body; X is a shoulder under the bonnet seat, which when screwed on its seat makes a metal to metal steam-tight joint.



CROSS-SECTION OF A NEW PACKLESS VALVE

The outstanding feature of this valve is the conical stem, 2, with its shoulder at the bottom, which seats into a steam-tight joint. The cone and shoulder are accurately finished to prevent the wedging action inherent in a conical joint of this kind. The stem nut, 6, is locked in place to prevent its movement with the stem insert, 5. The stem is non-rising, which adds to its claim to fool-proofness.

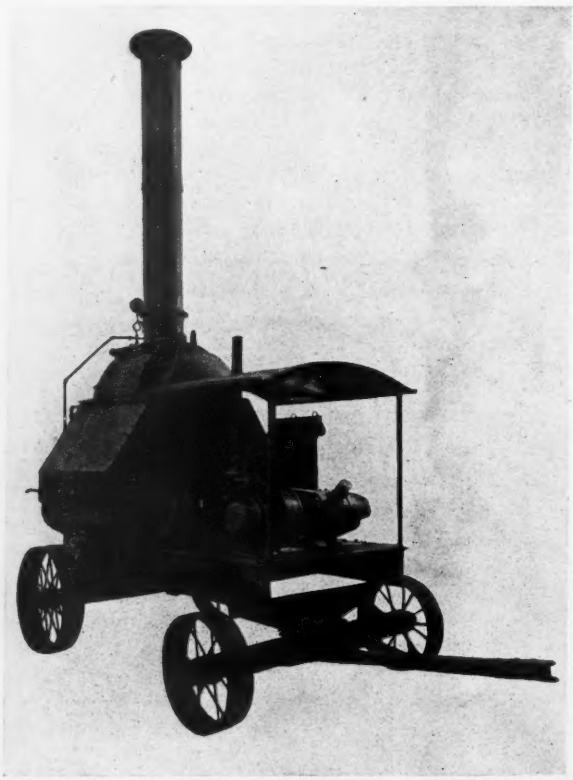
An important feature of this device is that it can be fitted to any standard valve body. This fact enables it to be installed in a piping system without the necessity of entirely dismantling the whole system, throwing out expensive bodies and piping.

It is surprising to note the great loss incurred through various small leaks that occur throughout almost any plant. These losses, while apparently trivial in themselves, represent an aggregate loss that cuts deeply into the coal pile and the pocket book. Obviously anything that will cut down these losses is doing a great service and is worthy of consideration.

Dynamobile for Mining Work

THIS NEW mobile power was designed and built for driving the small portable conveyors used in mining in South Africa. Previously, power for this purpose was furnished by the old-fashioned reciprocating engine and portable boiler, with belt and pulley transmission to the conveyor. The object of the dynamobile is to realize the utmost economy in generating power, and high economy and great flexibility in delivering that power to the driven mechanism.

The dynamobile consists of a special type of water tube marine boiler, a steam turbo-generator unit, switchboard, boiler feed pump, feed-water heater, condenser and, where the highest economy is sought, a super-



THE DYNAMOBILE, A MINIATURE POWER PLANT

heater—all mounted on a steel frame carried on wheels. It is extremely simple in construction and in operation, is free from vibration, and is practically "fool-proof" in construction.

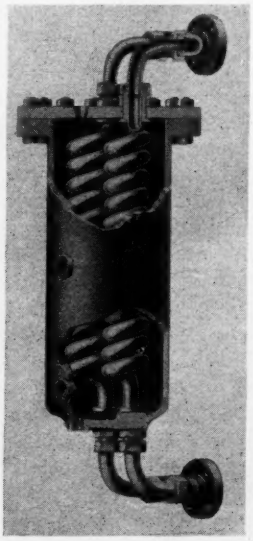
In the dynamobile illustrated, the boiler was designed for burning wood, the combustion chamber being unusually large. But the outfit can be furnished for burning any kind of fuel. The combustion chamber is entirely surrounded by the water-filled steam generating parts of the boiler, not only assuring high economy, but also doing away with all fire brick lining. The latter feature is of special value in a portable plant, as transportation over rough roads would break or dislodge a fire brick furnace lining.

The high efficiency of the boiler and turbo-generator set, and its compactness and light weight, makes the dynamobile a most economical and desirable unit for portable power purposes, as it can be located near its source of fuel and its power electrically transmitted to any reasonable distance with minimum loss. The outfit illustrated is of 10-kw. capacity. Larger units up to 200 kw. are furnished, either alternating or direct current.

Preheating Fuel Oil for Boiler Furnaces

FUEL oil which is now being furnished to power plants for use in boiler furnaces is of a very heavy grade and it is necessary to preheat this oil before it will flow readily to the burners and in order to insure proper vaporization.

In this connection, it is interesting to note the fuel oil heater illustrated herewith, designed for this purpose. The coil construction results in very high efficiency and eliminates any possibility of strain on coil joints. High-pressure steam is generally used for heating of this fuel



FUEL OIL HEATER

oil and the condensation is returned to the boilers. It is, therefore, important that precautions be taken to prevent contamination of this high-pressure condensate by the fuel oil. This is well taken care of in this heater by the patented connections which are so designed that there are no oil joints inside the steam space. Therefore, the possibility of contamination of the steam condensate is absolutely eliminated.

CANADA is now said to have a per capita water development second only to Norway. With 19,500,000 hp. available, she has developed 0.26 hp. per capita as compared with 0.54 hp. per capita for Norway and 0.07 hp. for the U. S. A.; but the United States has 30,000,000 water horsepower available and in this respect leads the world. The greatest possibilities in Canada are in the Toronto and Montreal districts, but Manitoba and British Columbia have large amounts of water power available.